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PAPERS ON POST-WAR PROBLEMS

I

STATESMANSHIP AND SPECIALIZED LEARNING

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Harvard University

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This series of addresses is devoted to the consideration of the ways in which learning derived from the systematic study of Arts and Sciences can profitably influence the reorganization of civilization in the future beyond this war In so far as the world of learning today possesses a capital city, Boston with its various neighboring institutions approximates to the position that Paris occupied in the Middle Ages Thus the importance of discussions initiated by these lectures cannot be doubted

This first lecture is concerned with a preliminary topic—namely, the wide influence of social coordination on every feature of human life, and by contrast the specialized limitations of every type of learning There is thus a gap between Statesmanship and Learning

Our first impulse is to deny this gap We point to the various departments of social sciences which exist in every university in the neighborhood of Boston There are even departments for the training of government officials This is true and these departments are doing a good job But their purpose is very restricted They *either* deal with very wide generalities concerning human existence, *or* they are confined to the specialties of some particular type of social coordination, for example, life in some South Sea Islands, or life amid the governmental activities at Washington, D C My point is that a survey of the World between the South Sea Islands and the District of Columbia in the United States, discloses a most perplexing number of types of social organization The two phrases—namely, 'social coordination' and 'social organization'—are apt to be misleading, by reason of their omission of any reference to the *activity* which is an essential character of life The term 'social cooperation' is nearer to the truth in expressing the problem of human life We are apt to think of change in the past as the substitution of one static system in the place of another static system A great deal of learned history supports this false perspective When I look back upon my own young life during the remote period of the eighteen-seventies, it was largely dominated by the study of history. But curiously enough in my imagination History ended with the Battle of Waterloo in the year 1815 Since then, the generations of my grandfather, and my father, and my own young school companions, were just living This process of living was not History It was mere daily activity History in my imagination was concerned with the conflict of static organizations such as England, France, Spain

The dispatches of statesmen unconsciously falsify contemporary life They have to take the general set-up of emotional activity for granted and conceive of the adjustment of detailed consequences. But in altering the details the whole emotional structure is affected For example, consider this country in the decade from 1860 to 1870 There was a desperate struggle issuing in large-scale changes But the importance of these changes consisted in the deep transformation of emotional relations The conclusion from these considerations is the importance of the Arts for the understanding of human life This is a meeting of The American Academy of Arts and Sciences During the last hundred years there has been a resolute attempt to turn Arts into Sciences The founders of this Academy were right, there is a real distinction between the two The Arts are concerned with the various types of emotional satisfaction, including the sense of correctness, and the Sciences with the various patterns which can be discerned and tested amid the activities of nature In the Arts the pattern is a construction explanatory of the emotional satisfaction, in the Sciences the interplay of patterns is the essential consideration The comprehension of existence requires the combination of Arts and Sciences In concrete human action, there is always a Science lurking behind an Art and there is always an Art stimulating a Science This is the reason why one Academy should include both Arts and Sciences

In the analysis of the necessities of human existence the Sciences take precedence On the other hand, when we are considering the purposes which should guide our action, the Arts are in the foreground, and Sciences in the background determine methods of procedure towards the goal defined by the Arts Of course if our actions are predetermined in every detail, this whole discussion is a silly make-believe which we cannot avoid

because it is predetermined by the frivolity of the Universe. I rather suspect that this is the predominant doctrine in this audience. You must forgive me, because it is predetermined that I proceed on the contrary hypothesis

The Arts take many forms—painting, sculpture, music, the analysis of the beauties of nature, cookery, and dancing, and architecture, and the decoration of the human body The two Arts most relevant to these discussions of our Academy are aspects of recollection and anticipation, enlarged and stimulated by verbal expression—namely, History and Literature The essence of History is description of the physical activities of the mankind in the past, with their function of eliciting various forms of emotional experience The emotional experiences of mankind are essential to History For example, it is not the mere fact that two heads were detached from two human bodies that is History—the History is the emotional convulsion of the European world produced by the execution of Charles I of England, and of Louis XVI of France Of course it is the business of historians to make it certain that the heads in question were in fact detached from their bodies Thus the function of History is the display of emotion derived from verified facts Social Literature is very analogous to History, but it has a wider scope It is concerned with facts which might have happened, or perhaps did happen, and with the emotions which might have been derived from those facts But in another sense, such Literature has a narrower scope than History Such Literature must in some sense be believable, whereas experiences of human beings in fact develop beyond all powers of conjecture Thus Social Literature is conventional, while History exceeds all limitations of common sense

In this short discussion of the function of the Arts in the interprétation of human behavior I have been using the term 'emotion' in a very extended sense, to include all activities of feeling and discrimination which lead to action, enjoyment, or purpose

Science is concerned with the relatively stable patterns of activity which in fact dominate existence so far as we can observe it. Such stable patterns are essential factors for the determination of human behavior But our scientific knowledge is only partial, and is restricted to average results Science knows nothing of detailed eccentricities or of the gradual loss of stability as some patterns vanish and give place to others Some type of eccentricity in the past is then becoming normal. In this characterization of science I am merely agreeing with a statement by the late President Eliot of Harvard in one of his letters, written many years ago I refer to him, because among other great qualities he was the incarnation of sound sense

After this preface we can now turn to the function of this Academy in the present crisis of human existence

Human beings are complex, various, delicate, excitable, and purposeful They require a stable social organization in order to preserve them, and a large variety of opportunity to elicit their individual capacities But these requisites are ideals What in fact we can hope for is a sufficiently stabilized society to preserve life, with some very limited opportunities for the expression of individuality. This second requisite is the meaning of freedom

These practical limitations of freedom make it necessary that those types of opportunity which a social system embodies should be relevant to the dominant desires of the populations concerned It is not true that every society exhibits the same predominant desires among its members. Thus the first step in political wisdom is to recognize this astounding distinction between social groups

Almost all effective thought belongs to one or another of two extremes namely, either complete abstraction from any special circumstances or complete concentration upon one special group of occurrences Induction is an effort to broaden the speciality of concentration Experience has proved that induction is a very slippery customer. The greatest success in its use has been to suggest some broad abstraction such as the notion of Genera and Species, or the doctrine of Gravitation combined with Newton's Laws of Motion Neither of these abstractions is quite true; but they have created modern science For political thought induction from one society to another is most dangerous It is useful in widening the range of imagination; but its naive application is fatal

A minor incident mentioned in the newspapers a few weeks ago illustrates this point. The America Government, pursuing the doctrine of Freedom, of which it is so justly proud, is arranging for the emancipation of the Phillipine Islands from American control This is a splendid example of a noble principle But it turns out that one of the smaller islands is inhabited by people of different origin, different habits, and different beliefs, from the general population These people of that Island have been completely satisfied with the

American supremacy. their ways of life are protected. But they view with horror subservience to an independent Philippine Government It means destruction to them This is a minute illustration of the whole problem of political reorganization.

Of course there is nothing insoluble in any one of these problems. But a simple-minded approach to practical politics is disastrous In each particular case there are always special factors which must not be neglected.

And yet, when all this has been said, the large generalizations of science founded upon wide abstractions, only partially relevant to any particular case, provide the essential basis for all sociological re-construction Within this century, science has provided new techniques, throughout its whole range from medicine to engineering, which are producing the greatest sudden revolution ever experienced in the habits of mankind The world has shrunken in size, and has expanded in opportunity Today the adventure of ideas is the discovery of opportunity

Our discussion now passes to the special problem of political reconstruction after the war This preliminary address is only concerned with the general outlook

We shall be faced with a completely disrupted social system, in confusion physically, emotionally, and ideologically This statement certainly applies to Europe, and to large portions of Asia and Africa Also it must be remembered that sociological disruption is the most contagious disease known to mankind Thus the first requisite is that order be imposed There can be no civilization apart from a well-organized system of inter-related activities, within which the intimacies of family life can be developed

Human life discloses many types of social order existing in the world, and—what is more perplexing—a great antagonism between adjacent groups in respect to differences of kinds of order, kinds of emotion, and of individual human beings produced by those various types. The love of humanity as such is mitigated by violent dislike of the next-door neighbor

For this reason, no single world-wide solution of the social problem can be successfully adopted Each special district must be studied with a view to the immediate solution applicable to it There can be no one general system of social coordination which does not destroy the special capacities of smaller groups. The essence of the world-wide sociological problem is the study of the modes of grouping mankind subject to some coordination of the various groups. Of course, this conclusion is a commonplace for all successful government. In this country, there are forty-eight States, and the District of Columbia, all supervised by the Central Government Also in each State there are cities, counties, and townships, each with its freedom of action within limits

Thus there must be a careful study of the possibilities of grouping, and of coordinating groups in different areas—for example in the Mahometan world of the Middle East, including Egypt, and in Central Europe stretching from the Baltic to the Aegean Seas with Russia and the Mahometan world on one side, and Germany and Italy on the other side There is Western Europe, with its various groupings Also there is the coordination of these groups

But we have omitted the fact that owing to modern techniques the world in the future will be immeasurably more compact than in past history India, and China, and the Oceanic Islands of the Eastern and Southern Oceans, and the two Americas which separate the ancient East from the ancient West, will be in essential, immediate connection with the small European and Mahometan Worlds, which first claimed attention It is here that this Academy is of importance Traditional statesmanship must be infused with the dramatic novelty which the immediate future presents Among the people most responsible for this duty are the members of Academies of Arts and Sciences They can compare the modes of action in the past with the novel possibilities of the future It is their business to inform the populations and to guide the statesmen Above all, it is their business to cooperate with each other, and not to exaggerate the petty views of the Universe which their own specialties present

A stable order is necessary, but it is not enough There must be satisfaction for the purposes which are inherent in human life Undoubtedly the first essential requirement is the satisfaction of the necessities of bodily life—food, clothing, shelter. These economic factors are dominant up to the level of moderate enjoyment They then almost suddenly become the mere background for those experiences which form the distinction between mankind and the animal world It is the imaginative originality of mankind which produces ideals, good or bad We live guided by a variety of impulses—towards loving relationship, towards friendship, towards other types of enjoyment such as games, art, ideals of mutual enterprise, and ideals

disclosing some sense of immortality. This intimate development of human experience enters into political theory as respect for each individual life. It demands a social structure supplying freedom and opportunity for the realization of objectives beyond the simple bodily cravings

Of course any one group of human beings, however large, has a very finite set of appetitions, depending on past history and on the sort of prevalent ideals In every social system there are exceptions, mostly foolish but some of them beyond price It is of the essence of good government to provide some adequacy of satisfaction both for the large communal motives, and for all reasonable exceptions on which progress depends. It cannot be repeated too often, that the only security for progress is a sincere respect for each individual human being

As we approach these problems the first words that occur to us are 'freedom' and 'democracy' The preceding discussion has been devoted to elucidating the fact that 'freedom' apart from relevant 'opportunity' is a meaningless notion Robinson Crusoe could do what he liked on his island but, until the savages turned up, there was nothing for him to do The history of mankind with its wars is the tale of groups of people seeking opportunity by the oppression of their neighbors Sometimes these wars sink into minor disturbances and are conventionalized, as in the late middle ages and in the eighteenth century

The enthusiasm for crusades—Mahometans attacking Christians or Christians attacking Mahometans—illustrates the poverty of life in the Middle Ages Also slavery, or half-slavery, by eliminating the claims of a large portion of the population, preserved the limited store of opportunity for the fortunate minority Today the notion of a master-race is being revived, and most of us are agreed that it means the moral degradation of mankind.

Within the last four centuries there have been three dramatic disclosures of new large-scale opportunities I put aside the Italian Renaissance for it only concerned a fortunate minority It was the last spurt of the Middle Ages Thomas Aquinas would have enjoyed it.

The first disclosure was the discovery of a new world—namely the half-empty continent of America, as the immediate result of the new technique of oceanic voyaging The real discovery was in fact the new art of navigation, and America was the first gift derived from it. The history of civilization opens a new chapter at this period, by reason of this increase of opportunity. The problem of existence was not solved, but hope entered into human life as never before. The three countries most concerned—namely, Spain, the Netherlands, and England—for the period of about 150 years starting with the sixteenth century, exhibit a stage of excited hopefulness, while unfortunate Germany was torn to pieces by disputes inherited from the Medieval World France was balanced between the two periods, and developed the brilliance of the old European civilization The intensity of the French Revolution showed that novel opportunity had not penetrated throughout the nation

The second enlargement of opportunity began about two and a half centuries after the first It was the industrial revolution which gradually developed from the middle of the eighteenth century, with its two culminations in the invention of the steam engine, and the invention of the railway. Human life was transformed

I am inclined to believe that its best effect was in opening the whole extent of North America to the European population This was due to the steamboat and the railway But nothing great in human history is due to a single cause, and we must also add the influence during the American Revolution of great statesmen guiding a peculiarly intelligent people

At least, the new techniques transformed life throughout the world, more especially in Europe and America In western Europe during the second quarter of the nineteenth century there was a period of optimism The problem of human life seemed to have been solved, and the first International Exhibition in London, during the year 1851, celebrated this glorious triumph with the creation of the famous Crystal Palace

Alas, something was missing It may have been the want of intelligence among statesmen and industrial leaders It may have been that the development of techniques was less fundamental than it seemed Whatever the reason, the Crystal Palace, very symbolically, has been burnt down; and the nations are now struggling to avoid the ancient evil, which is the selfish mastery of the few over the many.

At the present time, we are in the first phase of the third enlargement of opportunity, perhaps the most important crisis in the history of civilization.

The intellectual development of mankind, with its self-conscious criticism, has a recent growth of some five or six thousand years. Its earlier stages seem to consist of traditional legend with the min-

imum of coordination But about two thousand six hundred years ago, a widespread movement of critical judgment on the nature of things had established itself. The European races derive their special systems of thought from the brilliant races in the Eastern Mediterranean and the Near East, more especially from the Greeks But in the course of ages the centre of activity has moved backwards and forwards through many races from Mesopotamia to the Straits of Gibraltar It has also spread northward There were analogous movements in China and India; and the three intellectual growths fed each other intermittently But European systematic thought has shown the greatest energy both in self-criticism and by its contact with practical activity Today it is refashioning the ways of thought and action in every civilized race of the World

The result has been a gradual broadening of opportunity But this growth has been intermittent, and wavering Slavery became serfdom, and serfdom became free laborers on the edge of starvation The status of the workers improved, although the slums of industrial cities disgraced industry Indeed at the very moment when the Industrial Revolution was in its prime, Malthus managed to prove that the mass of mankind must always live on the verge of starvation He was only answered by the nearest approach to an appeal to Divine Providence that men like John Stuart Mill dared to make Every factor involved in human existence is too variable to justify these sweeping statistical deductions based on past experience

As an historic fact, the gradual introduction of novel techniques has broadened the amplitude of opportunity for the mass of mankind, slowly and waveringly Within the past five or six hundred years there have been certain crises in this slow advance, due to these novel techniques These critical techniques are not the most interesting facts for abstract thinkers, but their immediate effect was overwhelming For example, the evolution of trans-oceanic navigation, as distinct from coastal voyaging, is not very interesting for abstract learning But it changed the history of mankind Again, the thoughts of Galileo and Newton were of supreme interest, but the habits of mankind between the dates 1690 and 1750 were very slightly altered The total effect was that fortunate people had a new theme of intellectual enjoyment. Indeed within this period the introduction of cheap spirits, such as gin, probably did more harm to English life than all the noble thoughts of the Royal Society did good But the growth of Science did arouse an alertness of intellect The result was the Industrial Revolution in the hundred years between 1750 and 1850

Today we are at the beginning of a new crisis of civilization, which gives promise of producing more fundamental change than any preceding advance The growth of science in every department of thought seems to have reached a stage where the whole spread of knowledge discloses new possibilities for practice This holds throughout the whole range of activities, from medicine to engineering, from mining to aerial flight, from the use of the microscope to the waves of energy from remote nebulae, from psychoanalysis to geology The whole of human practical activity is in process of immediate transformation by novelties of organized knowledge It is no longer a question of a new detail such as gunpowder, or printing, or the power of steam, or the novel machinery, or a new aspect of religious thought Today, the whole extent of learned thought is transforming every activity of mankind This is the largest epoch in human history Historical knowledge is essential, but very dangerous The old phrases are misleading. For example, in this country it is no longer sufficient to tell young people to 'Go West in a covered wagon' In my own country (England), the old habits must be completely reformed Again, we must insist, History is essential for the direction of action but its naive application is very dangerous

Still more dangerous are the simple-minded generalizations of specialized scientists beyond their own limits of special knowledge The truth is that we must work together Historians must study the new possibilities of action; and scientists must learn the old chequered history of human emotion passing into large-scale social activities

There is one prophecy upon which I will venture It is that throughout the vast land-areas of the Old World—Russia and China, for instance—the example of North America will be predominant. Perhaps also America has something to learn from Russia and China.

Also, forgive me when I conclude with a confession of personal political faith I do not trust any extreme, abstract plan of universal social construction. Such plans are important for the stimulation of the imagination But in practice every successful advance is a compromise The general ideal is the wide diffusion of opportunity The sort of opportunity relevant to each special case depends on special characteristics of the populations involved.

DISCUSSION OF PROFESSOR WHITEHEAD'S PAPER

By Samuel H. Cross

Harvard University

Presented November 12, 1941 Received April 2, 1942

Professor Whitehead's talk laid down certain general principles which we may recall tonight with profit You remember his statement that human beings require a stable social organization in order to preserve themselves, and a large variety of opportunity to elicit their individual capacities. "But," he continued, "these requisites are ideals What in fact we can hope for is a sufficiently stabilized society to preserve life, with some very limited opportunities for the expression of personality" In this last the speaker discerned the meaning of freedom He likewise pointed out that the practical limitations on freedom "make it necessary that the types of opportunity which a social system embodies should be relevant to the dominant desires of the populations concerned" He reminded us that after the war "no single world-wide solution of the social problem can be successfully adopted," and that "each special district must be studied with a view to the immediate solution applicable to it" Professor Whitehead also made the point that 'freedom' apart from relevant 'opportunity' is a meaningless notion

Here, it seems to me, is a factor that was not provided for in the settlements after the last war. We established 'freedom,' or 'democracy' (if you like) in a variety of countries, including Germany itself, but without the economic opportunity to make that freedom worthwhile

In Germany, for instance, the depreciation of democratic institutions (specifically, popular representation in the Reichstag) which set in with Bismarck and continued during the entire reign of William II turned men of energy and intelligence away from political activity into scholarship, finance, and industry, while the jingoistic propaganda of the nationalists tended to increase the authority of the crown, the bureaucracy, and the military caste. Hence when, in the fall of 1918, an attempt was made to transform Germany into a democracy, neither trained democratic statesmen nor a citizenry practised in independent thinking were available to make the system work. At best, an appreciable lapse of time was required before an understanding of the operation of democracy could take root. But this understanding could not be promoted unless the elements of the population likely to achieve it were encouraged and strengthened by the "opportunity" which Professor Whitehead mentioned For as long as democracy limped because of economic disabilities wished upon it by the very foreign powers which had insisted upon its establishment, it had no vitality or popular appeal, and new weapons were thus placed in the hands of its opponents day by day until the catastrophe of 1933 In general terms, then, given a democratic victory in the future, it will not make much difference what sort of social and political system we establish anywhere unless they possess economic vitality and soundness

Professor Whitehead referred to ideals. I mistrust ideals in the minds of people who regard the means of approaching them as equally absolute with the ideals themselves, and therefore resent any change in procedure It is, for example, an American ideal not to engage in a foreign war, and a corollary to this ideal is the present reluctance to admit the thought of a new American expeditionary force on European or other foreign soil Aid to the embattled democracies "short of war" was another ideal, and many American citizens consequently circulate with blinders on, refusing to admit that the ground has shifted In this instance not only has the procedure become impractical, but the ideal itself is gradually proving untenable The combination of a specious ideal with emotional involvement and motives of personal interest is thus a sure prescription for fallacious public opinion

The problem of combining a stable social organization with a practical volume of individual opportunity is perennial, but the means of solving this problem inevitably vary For any human problem is eternal, but human solutions, being at best mere expedients, are only temporary, since time shakes the material and psychological bases on which these solutions are set, even though the ideals behind the solutions remain fixed

We therefore ought not, I think, to be so simple as to persuade ourselves that there will be any universal finality about the solutions reached after this war Hence the slogans chosen to express its aims might well be a little less than categorical. It is perhaps permissible for a propaganda agency or a publicity man to talk glibly of "making the world safe for democracy" or fighting "a war to end war." The former Allies made the world

temporarily safe for British and American democracy, but by failing to provide the Germans with the opportunities to which Professor Whitehead referred or to realize that, as he reminded us, there can be "no *single* world-wide solution of the social problem," they managed ultimately to jeopardize practically every other previously existing or freshly-created democratic structure The manifest result has been a decline of confidence in democracy and a tendency to disparage any sort of freedom as against security, even when combined with loss of free speech and self-government

Professor Whitehead wisely pointed out that "history is essential for the direction of action," but that "its naive application is very dangerous" because "the old phrases are misleading" This I take to mean that the wisdom of knowledge is not always coupled with originative or inventive imagination, so that it is a human propensity to yearn for the recreation of the *status quo ante* It is, however, encouraging that the statesmen of the dispossessed nations who are now passionately discussing their various problems show little disposition to be fettered by concepts which the past has proved to be faulty For the future of Central and Eastern Europe they are, in fact, eagerly debating various types of federation, and thus wisely working to satisfy Professor Whitehead's call for coordinated groups

On the other hand, we may talk eagerly of some ultimate form of Central European or Danubian federation But almost superhuman wisdom and patience will be required to reconcile national aspirations and jealousies which will be revived as soon as some prospect of liberation appears Statesmen who regulated the destiny of these countries before the catastrophe may not necessarily be possessed of sufficient ingenuity to master new conditions, and those patriots who have withstood the rigors of enemy occupation may not enthusiastically accept the authority of those of their luckier fellow-citizens who managed to spend the war period in the precarious comfort of London and New York The most zealous efforts of leaders in exile must be directed toward understanding and interpreting the sentiments of their compatriots under subjection in order to present the latter's needs and desires accurately when restoration becomes possible Countries lately occupied will have to arrive at some degree of understanding with neighbors who not only were not occupied, but even, on grounds of national interest or cruel necessity, may have been forced to live in accord with the aggressors. The solution for Central Europe lies, not in clinging to points of conflict, but in removing them by common understanding and concession

However baffling these tasks are, they must be faced with determination and imagination by men ready to reject outworn tradition and to combine the lessons of the recent past with rational ideals of a better future in the creation of a peace of some duration It is vital that no settlement after the present war should be vitiated either by the dire influence of remote historical events or by the perpetuation of more recent sources of embitterment The crying need is for a spirit of healthy compromise, so that equal rights and opportunity may be established for Central Europe once the most dangerous points of contact between German and Slav are removed

Such a rational spirit of compromise does not, by any means, preclude a decent respect for the problem presented by long standing German areas of colonization or regions of recent German infiltration in districts where the German element is surrounded by a majority of different culture and language The Nazis themselves have not refrained from drastic measures of resettlement and transplantation to regulate such situations in their own interest, and they have quite openly not only declared, but also put into practice, their deliberate intention to wipe out the Slavic intelligentsia of Poland and Central Europe and to turn their Slavic subjects into a class of agricultural and industrial helots In any peace settlement, whatever German action has been taken toward the realization of this dastardly project deserves the most ruthless liquidation, including removal of German minorities and the settlement elsewhere of such German immigrants as have been purposely introduced to form the nucleus of a new ruling class This process similarly entails the removal of German population from areas historically productive of repeated international collisions, particularly the Baltic coast from Danzig to Memel and its hinterland It does not mean, however, that these transplanted groups should be pushed back into an overcrowded Reich, but rather that, in compensation, appropriate colonial areas should be ceded to Germany which will absorb and employ its excess population, thus obviating the chances of its subsequent violent expansion at the expense of any neighboring European state

But the lessons of the past go further still The causes of the present war may be summed up in the fateful triad of revenge, strategy, and nationalism If there is any outstanding conclusion to be drawn from the experience of the last twenty

years, it is that setting up a series of economically weak national states solely on the basis of romantic ideals, popular traditions, and strategic aims is no guarantee of peace. To bolster up their weak budgets or to favor local industry, such states erect tariff barriers which prevent the normal flow of commerce and exchange on which their very life depends. If their territories contain linguistic minorities, the latter are discriminated against in business and politics until they seek support from the nearest large state to which they are akin, and eventually provide that state with a natural pretext for intervention. In order to counterbalance their more powerful neighbors or checkmate some adjacent state with good diplomatic connections, these small states unite in ententes and alliances which become the pawns of international politics, and give the statesmen of these minor organisms a chance to assume positions of influence for which they may not be qualified by experience or vision. But with the progressive industrialization of the world and the need of reapportioning both essential raw materials and export markets, there are enough problems confronting the major nations in their dealings with one another without the additional risk of becoming embroiled over the petty aspirations, mistakes, and quarrels of these minor units.

In their own interest, therefore, such small states must inevitably resolve to combine into some form of federal organization. But such a federation cannot live and thrive unless it rests on the enthusiastic support of the masses, who need to be convinced that they are going to get a square deal from a government in which they have a direct stake through universal suffrage and graduated representation. We all talk glibly of democracy, and any average American knows well enough what he means by it: no vague abstraction but representative government, the secret ballot, unrestricted popular education, freedom of speech and worship, equality of opportunity in proportion to a man's capacity, absence of galling government restraints upon a man's private life, the state created for the service of its citizens, not as a cruel master of the individual's work and brain—in simple terms, precisely what one breezy Westerner called "the privilege of speaking one's mind and eating regularly."

Yet it is an open question whether the same definition would always stand when democracy is translated to Central Europe. Democracy does not mean government by an oligarchy of army officers, landowners, country squires, industrialists, or intelligentsia, nor does it offer license for the impulsive activities of small political parties, each too doctrinaire to make concessions to its rivals or to do more than form a temporary part of some short-lived parliamentary majority. For the resulting inefficiency of the whole governmental machine is directly paid for by the declining prosperity of the masses, who then become the easy prey of discontent and of hostile propagandists from right or left. The essence of democracy lies in its permanent obligation and capacity to correct and reform itself. No great institution becomes static unless it has begun to decay, and if a democratic nation does not remedy its own defects, hostile ideologies will use them as effective weapons against it. A federation of this nature, then, must not only be economically sound, but it must also feed on a healthy popular loyalty.

Finally, however bitter may be the resentment felt by the dispossessed nations against the Germans and especially against the present masters of the Reich, it may be set down as axiomatic that, even though certain transplantations of German minority groups appear imperative, a generally punitive peace settlement should be ruled out as opposed to the common interest of the modern world. Every devotee of democracy resents German pretensions to superiority over the Slavs and, conversely, no peace can be enduring which reduces eighty million civilized people to a state of political vassalage. It is likewise impossible to reverse the current of history entirely by partitioning a homogeneous nation now accustomed to unity. Nor can peace be restored if such a nation is deprived of adequate trade outlets or raw material supplies. If a virile nation is barred from colonial expansion, it will expand at the expense of its immediate neighbors: hence certain colonial readjustments are vital. To speak of annihilating such a nation is futile and barbarous. It was Masaryk himself who said, "We often confuse hatred for another nation with love for our own." As soon therefore as the Nazi system reveals its essential weaknesses under the pressure of ultimate reverse or defeat, the younger German generation, now so devoted to it, must immediately be given concrete proof that democratic ideology is actually superior to the false philosophy for which they have been making so many useless sacrifices. At this moment we may not foresee exactly what form of government is best for the German nation. But whatever German government is set up after a Nazi debacle must not be paralyzed by galling restrictions and a sense of inferiority.

These are some general and practical reflections inspired by Professor Whitehead's paper. As scholars we must think on these things and make our conclusions known, lest the adjustment of critical problems is left by default in the hands of those louder-mouthed and less informed.

DISCUSSION OF PROFESSOR WHITEHEAD'S PAPER

By Hans Kelsen

Presented November 12, 1941 Received April 2, 1942

Any discussion of post-war problems is possible only under the presupposition that the United Nations will win the war and that they will succeed in destroying national socialistic and fascistic régimes, as well as military dictatorships, wherever they appear in Europe or Asia Should this not be possible, then there is no hope for this better world which we have in mind when we speak of post-war problems

In our discussion, however, we will not proceed from this but from the other possibility, the realization of which we fervently hope for the victory of the United Nations The new world order to be established shall be a community of States within which war will be excluded, a community the prosperity of which will be guaranteed by a permanent peace, "a peace which will afford to all nations the means of dwelling in safety within their own boundaries, and which will afford assurance that all the men in all the lands may live out their lives in freedom from fear and want" (Point 6 of the Atlantic charter)

Such an order is possible only under two fundamental conditions First there must be, as far as possible, political and economic homogeneity among the states forming the community There is little reason to expect communist or state capitalistic states and states with a liberal economic system to exist side by side, even in a fairly loose international organization, as to expect democratic and autocratic states to combine in an enduring union Second a satisfactory regulation of the territorial relations of the states forming the community is imperative. This kind of regulation is possible only if it is conducted as extensibly and honestly as possible according to the principles of the right of self-determination of the peoples. Where minorities are unavoidable, they are to be organized as entities with constitutional rights The treaty establishing the international community will grant them the status of personality in international law, so that they will have the right to call upon an international Court in case of the violation of the provisions for minorities

As far as the first condition is concerned, a great difficulty arose when the Soviet Union became a full Ally of Great Britain and the United States of America in the war against Germany and Italy We must reckon with the necessity of admitting the Soviet Union into the new international community, and we cannot expect that the Soviet Union, especially after a victory in which she had a great share, will abandon her communistic and authoritarian régime However, this difficulty is perhaps not so unsurmountable as it seems at the present time On the one hand, the economic system of the Western Powers has a clear tendency towards state capitalism, and on the other hand, a victory of the democratic states will strongly influence the political system of the Soviet Union, whose written constitution already has taken on a democratic character It will only be necessary to conform the political practice in the Soviet Union to the wording of its constitution

Much more serious, however, are the difficulties which confront the fulfillment of the second condition, namely the principle of self-determination of the peoples, especially "the right of all peoples to choose the form of government under which they will live" (Point 2 of the Atlantic Charter) It is almost impossible to found the peace on this principle Of course, the peace treaty will immediately restore Norway, Denmark, Belgium, Holland, Luxemburg, Poland, Czechoslovakia, Yugoslavia, and Greece as independent states in full accordance with the free will of the peoples concerned These peoples will undoubtedly reestablish their democratic constitutions, or enact such where before the war more or less fascistic elements prevailed, as for instance in Poland and Greece But the major part of Europe offers no guarantee that its peoples will voluntarily and spontaneously return to democracy and peaceful cooperation with the other peoples Let us constantly keep in mind that there exist in Europe eighty million Germans, more than forty million Italians, twenty-six million Spaniards, fourteen million Rumanians, thirteen and one half million Hungarians, who have lived for years under totalitarian régimes Especially the youth of these countries, educated by national socialistic and fascistic teachers, does not know the ideal of democracy and international peace. Let us not forget that Hungary, Bulgaria, Slovakia, Croatia and Finland are now fascist states, or are under the influence of Germany and Italy, and that, last but not least, a great part of the population has, rightly or wrongly, lost its faith in democracy As far as Japan is concerned, we all know that it is and has been, for many years, under a military dictatorship and that its younger

generation is completely alienated from democratic ideas

Immediately after victory, it will not be possible to organize this better world for which we are hoping A transitional period will be necessary, characterized by the following facts complete disarmament of all states now under national socialistic or fascistic régimes or military dictatorship, political and military control of these territories exercised by a body of representatives of the United Nations, above all in order to win the population of these countries for democracy and international cooperation, and to educate their youth for these ideals No illusion is more dangerous than to assume that these Germans and Italians, these Spaniards, French and Rumanians, these Japanese, (more than two hundred million people) are democrats and pacifists, and that only their dictatorial masters prevent them from having the same political organization as this country or Great Britain

How long will this transitorial period last, and which is to be the political form of the Union which finally may be established? The first question cannot be answered now Everything depends upon circumstances which cannot be foreseen today As far as the second question is concerned, two different plans are suggested one is to reestablish the League of Nations, the other to create a completely new international organization The difference between these two plans is, however, not so great as it might appear at first sight For, should the League of Nations be revived, it could never be the old, it must be an entirely reformed League of Nations And if a new international organization is to be established, the lessons which can be drawn from the breakdown of the old League will be indispensable for building up the new community

The decisive question as to the constitution of the new League refers to the degree of centralization which shall and can be realized in the law-creating and law-applying function of the new community It is the question whether the international community shall or can have the character of a Federal State or only of a confederation of States There is no doubt that the aims of the intended organization would be achieved in the best and most effective way if this community would be organized as a Federal State, that means the establishment of a World Parliament and a World Administration which is, of course, incompatible with the sovereignty of the member states of the Union On the basis of our experiences with attempts of creating international organizations, the idea of a World Federal State must be considered—this is my personal opinion—a utopian scheme Even if such a Federal World State should be desirable, it is, seen from a realistic point of view, quite unlikely that within a reasonable time great powers like the United States of America or the British Empire will unite with dwarf states like Denmark, Norway or Switzerland, that republics and hereditary monarchies will from one day to the next give up their sovereignty, will found a Federal State, will submit their own governments to a World Government in which all the members participate It is more than likely that this aim, if one accepts it as such, can be reached only in various stages From the political point of view, the only serious question is, *what is the next step on this road to be taken with a view to success?* Obviously, it can at first only be an international Union of States, a confederation of States, not a Federal State that one should set up It can be only a confederation of States, and not a Federal State, if the new community of states shall be created by an international treaty concluded by free and democratic governments and not by unilateral coercion exercised by a victorious power Such a Federation of States is not incompatible with the existence, within its framework, of closer and more centralized unions of single member states Such a closer union may be established especially by the United States of America, Great Britain and some others of the United Nations, and must be established if these states accept the responsibility of a political control of the vanquished countries

As far as the constitution of the wider League is concerned, the breakdown of the League of Nations has furnished us a valuable experience One of the most important, if not decisive, causes of its failure was a fatal fault of its construction, the fact that the authors of the Covenant placed at the center of this international organization not the Permanent Court of International Justice, but a kind of international administration, the Council of the League of Nations The Covenant placed the Council, not the Permanent Court, at the center of its international organization, because it conferred upon the League not only the task of maintaining peace within the community, by settling disputes and by restricting the armament of the member states, but also the duty of protecting them against external aggression This protection of member states against external aggression is possible only if the government of the League disposes of an armed force, if the League has its own

army, navy and air force Such a centralization of the executive power means the establishment of a Federal State Because it was impossible to organize the League of Nations as a Federal State, the League failed completely in its duty to protect the member states against external aggression The experiences of the League of Nations show that it is necessary to make a clear distinction between the maintenance of internal peace within the League, and protection of the members against external aggression, and that it is hardly possible to fulfill the second task by the specific means at the disposal of a universal international organization embracing many different states As long as it is impossible to constitute this union of states as a Federal State, it seems to be more correct to limit the task to the maintenance of internal peace, and to leave protection against external aggression to political alliances between the member states To maintain peace within the international community, its constitution should try to establish the strongest possible guarantee within the compass of international law the obligation of the member states to submit all their disputes without exception to the *compulsory jurisdiction of an international court* and to execute in full good faith any decision of the court That means that the members of the League agree to *abandon the use of force* in their mutual relations (Point 8 of the Atlantic Charter), except against a member which in disregard of its obligations refuses to execute a decision of the court or resorts to war or reprisals against another member, without being authorized by a decision of the court

If the treaty constituting the international community does not establish a central executive power, an army, navy, and air force of the League independent from the armed forces of the member states—a central armed force at the disposal of a central government—the decisions of the international court can be executed against a member state only by the other members of the community, if necessary by the use of their armed forces under the direction of an administrative organ, such as the Council of the League of Nations The Covenant of the League may determine the size and the organization of the armed force which each member state has to keep in readiness to execute the collective sanction according to the orders of the Council The Council may be authorized by the Covenant to appoint an organ whose function should be to control the military obligations of the member states and, if a military sanction is to be executed, to appoint a commander-in-chief of the League But the Council of the new League should be an auxiliary organ of the Court The fact that its task will chiefly be to execute the decisions of a court, will facilitate considerably the composition and particularly the procedure of this administrative organ, especially as its decisions must be adopted according to the majority-vote principle

A new League of Nations whose central organ was to be an international court with compulsory jurisdiction would constitute an extraordinary progress in the field of international organization It would be the technical realization of an idea which the Kellogg Pact first tried to put into operation the elimination of war as an instrument of self-help The Kellogg Pact could not succeed because it pursued its end with technically insufficient means The League here proposed would be an intermediate stage between the old League of Nations and a future World Federal State with a world government, an intermediate stage which is inevitable in the natural evolution of international law The next step, not the last one After we have succeeded in establishing an international community uniting the most important states of the world under a covenant instituting compulsory jurisdiction, and after this political system has worked successfully for some time, we can try to make a further step, we can hope to succeed in organizing a centralized executive power, a world police, and later perhaps a world administration under a world parliament

As far as the economic purposes of the new League are concerned, its constitution must contain certain provisions which guarantee to the members of the League the right "of access, on equal terms, to the trade and to the raw materials of the world which are needed for their economic prosperity" (Point 4 of the Atlantic Charter), and secure for all members "improved labor standards, economic adjustments and social security" (Point 5 of the Atlantic Charter)

But I would like to lay stress upon the fact that, contrary to a wide-spread opinion, it is not the economic element which determines the political one, it is the political element which determines the economic one If the history of the last decades has taught us anything, it is the primacy of politics over economics

It is a political task to win the war, it is a very difficult task, but even more difficult will it be to organize the peace

II

SOUTH AMERICA AND THE WAR

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South of the Rio Grande, there are twenty Latin American republics They contain an area larger than that of Canada and the United States They have one hundred and twenty-seven million people, only a few million less than the United States. However, the productive capacity of the people of Latin America is not as high as that of the people of the United States and Canada, chiefly because of the greater mechanization of the latter two countries Nevertheless, the people of Latin America can play and are playing a very significant part in the war efforts of the United Nations Though these countries have many manufacturing regions and industries, they are primarily producers of raw industrial materials and foodstuffs which are in great demand principally since the loss of areas in southeastern Asia

The impact of the present war on Latin America has been terrific, to say the least Of course, you all realize that the influence of the war on Latin American nations has not been as great as it is on the occupied countries of Europe and Asia—countries that have completely lost their economic status and their political and personal freedoms as well All the people of Latin America feel the impact of the war These countries have lost a considerable share of former markets for their products The people realize as the war progresses that victory for the Axis would also mean for them the loss of political and personal freedoms

In nearly every aspect the influence of the present war on Latin America has been different from that of the first World War During the first World War the shipping situation did not become as critical as it is at the present time There was little German organized activity in Latin America, whereas today Axis propaganda activities have been well organized and have penetrated most sections of Latin America In the last war Latin American countries lost a relatively small proportion of their European and Asiatic markets for industrial raw materials and foodstuffs Today these markets are completely lost to those countries, because of the effectiveness of the British and American blockades Despite the effectiveness of the Axis submarine campaign, the United Nations still control all the shipping lanes to Latin America

The Shipping Situation:—For cooperation in the war effort Latin American nations need shipping and need it badly All the large merchant fleets of France, Italy, Norway, The Netherlands, and the small merchant fleets of several other continental European countries no longer serve Latin America Neither does the large Japanese merchant fleet Much of the British merchant fleet has been withdrawn. Before and after the attack on Pearl Harbor, most of the United States and Canadian passenger vessels, serving Latin American countries, were taken over by the Navy and Army However, there is still a large freight tonnage serving this area Latin America has sufficient tonnage to carry only a small proportion of the commodities it can supply However, authorities state, that despite the submarine campaign, the shipping situation will improve Now that the people of Latin America realize that civilians in the United States must get along without many commodities, they do not feel so badly about their inability to secure consumer goods formerly obtained by means of foreign shipping

Axis Activities —Less than a year ago a rather important government official in Washington stated that Axis activities in South America were not well organized and would not amount to anything Recent events have proved that this official was uninformed of the situation and that he was entirely wrong in his statement

Conservative estimates place the number of Germans in Latin America at 3 million, the number of Italians is several times that of the Germans The Japanese in Latin America total about 330,000 Germans are concentrated chiefly in Brazil, Argentina, and Chile, the Italians chiefly in Brazil and Argentina, and the Japanese chiefly in Brazil and Peru However, Axis officials and propaganda agents are present in small numbers in all areas

Far more than the German and the Japanese, the Italian colonist has been assimilated in the countries where they have settled Most of these Italians do not want to have anything to do with the Fascist program in Italy and the greater program of the Axis powers Italian propaganda agents and officials have not been able to organize the Italian population. This situation,

however, is not true with the Germans and the Japanese

During the first World War the large numbers of Germans in Brazil, Argentina and Chile did not become disturbing elements for the governments of those countries Though some of these countries took up arms against Germany, the settlers gave no serious trouble. However, the situation of these Germans today is not comparable to that in the last war The Nazi officials and agents have organized all Germans According to the theory of the Nazis, all pure Germans and also all Germans of mixed stock are still German, no matter how many years they have lived in Latin America and no matter what intermarriages have taken place with non-Germans The German organization is centered in the embassies Without exception, German embassies have a larger personnel than other embassies In some centers, German personnel is greater than that of all other embassies combined In Buenos Aires, the German embassy has 150 persons as against 30 for the British That in Santiago numbers 40 persons as against 17 in the American embassy In all Latin American countries the organized Nazi party has been outlawed However, often in the same building with the embassy, are the offices of German Beneficent and Cultural Societies, which have taken the place of the old Nazi party organization In addition there are many hunting clubs, skiing clubs, church clubs, etc Through the embassies and these organizations, all Germans in Latin America are enlisted in Nazi propaganda activities In organizing the Germans, officials have used persuasion and force Persuasion has been eloquent, force has been effective All of these people are under the direct control of the German Foreign Office Their names are card indexed and classified in Berlin

Funds for Nazi activities have come from several sources Members of societies are assessed for 10 per cent or more of their income German firms and banks pay their toll Large sums of money have come directly from Germany Ostensibly, funds are collected for charitable purposes, for Winterhilfe and for relief of poor Germans in Latin America However, no accounting has been given Expenditures of these embassies are out of all proportion to German connections and business transacted In 1940–41 the German embassy in Buenos Aires spent 5,980,000 pesos, in contrast to 1,830,000 pesos spent by the British, during the same period Investments and business of the British in Argentina are more than 100 times those of the Germans

With characteristic thoroughness, the Nazis have utilized all means of spreading propaganda They have used the postal service, press, movies, radio, German schools, churches, and airlines, they also have put pressure on national leaders and minority parties in order to overthrow governments not in favor of the Axis program Sufficient time is not available for a detailed analysis of the various propaganda campaigns I should like to discuss briefly two types of activities·

German Mail Campaign —A well organized German mail campaign floods the various countries with books, pamphlets, letters, and postcards. Cards and pamphlets are widely distributed, not only to the Germans, but also to a large mailing list of influential sympathetic citizens This past summer, I saw in Lima and several other cities, a children's Spanish edition of the Life of Hitler Early last August, I was in Buenos Aires, when the Argentine officials impounded the sixty-seven pieces of supposed personal baggage of Ambassador Von Thurmann, which had made its way to Argentina by way of Japan When searched, it was found that the baggage was not personal, but that it consisted almost entirely of propaganda literature, done up in small packages with detailed instructions as to where to place the different packages, so as to be most effective In the same baggage, was found at least one high-powered radio sending set Obviously, Von Thurmann did not get this baggage The newspapers in Buenos Aires reported, that on the afternoon the police impounded the baggage, Von Thurmann was seen in his backyard burning huge piles of waste paper Until recently, the special air mail edition of the Frankfurter Zeitung has been sent by air mail to an unknown number of first citizens throughout several South American countries In July 1940, postal authorities in the Misiones territory of northern Argentina averred that 95 per cent, by weight, of all the mail handled in the territory was German propaganda

German Pressure on National Leaders —The German industrialist, merchant, and banker, as well as the personnel of the embassies, associate with the national leaders in the different countries. Nazi pressure on politicians ranges all the way from cajolery to bribery Decorations to army officers, free trips to Germany for generals and politicians, academic awards for scientists, scholarships to German universities, are gifts that have been presented with such grace that the word

"bribery" would appear rude. They win support by citing German successes, reiterating the certain victory of Nazi armies, and by emphasizing the fact, that those countries had nearly half of their foreign trade with continental Europe before the war, and will need the cooperation of German-dominated Europe after the war

Nazi agents stir up trouble between various factions in the governments In several instances, Nazi activities have been significant in the attempted *putschs* to overthrow governments in order to set up new governments in complete sympathy with the aims of the Axis powers In May 1940, investigators in Uruguay discovered a German document—a detailed military plan to seize Uruguay, to eliminate troublesome citizens, and to make the nation an agricultural colony of the Reich The congressional investigation, which followed, proved that the Nazi Party in Uruguay had branches and agents all over the country and collected toll from the members by persuasion and force The Nazi organization had supplies of rifles, machine guns, ammunition, and a well-organized bicycle corps. Like an earthquake, the disclosures shook the Baldomire Government of Uruguay to its very foundation, but the government weathered the shock, broke up the Nazi Party and arrested, tried, and deported eight of the accused men

Disturbed by rumors of German activity in the territory of Misiones, the Argentine Government in July 1940 ordered an investigation Nazi headquarters were raided—50 machine guns, 3,500 rifles, and much ammunition were discovered and sent to the national arsenal in Buenos Aires These revelations stirred up public demand for action Since then, numerous government investigations have uncovered subversive Nazi activities in several other provinces of Argentina

Plans for the *putsch* to overthrow the Bolivian Government last July failed completely, as did also the attempted *putsch* in Paraguay less than a couple of months ago

Japanese in Latin America cooperated with the Germans in making propaganda and in preparing for the attack on the United States Only recently, the Congressional Committee, investigating aviation conditions in South America, discovered that six Messerschmidt planes were recently flown into Colombia by Japanese pilots The planes and pilots later disappeared on German plantations in Colombia The same Committee learned that the Japanese had secretly stored 8,000 tons of dynamite at Medellin, Colombia, within easy flying distance from the Panama Canal They also discovered that Japanese and Nazi agents had established several secret air bases in Colombia, chiefly in connection with German plantations This past summer I saw two of these air fields in remote sections of southern Colombia During the past two weeks the Brazilian Government has uncovered a well organized plan of Japanese officials and Army officers to overthrow the Brazilian government upon receiving orders from Tokyo This *putsch* like several of those of the Germans has been nipped in the bud.

Accomplishments to Date —In the past two years much has been done to accomplish hemisphere solidarity and to obtain complete cooperation by Latin American nations in the war efforts of the United Nations Some of these accomplishments have been achieved so quietly that many people do not appreciate what has happened and do not see the full significance of them

Axis Airlines in Latin America —The Germans were the first to introduce commercial airline service between parts of South America On September 30, 1939 German and affiliated companies in South America had 25,700 miles of airlines The network connected all South American republics While many of these airlines were commercial in character, others were extended to remote places of the continent for strategic purposes only. Many airports were laid out on a more generous scale than is required for commercial use only. The lines have been operated without regard to profit In March 1940 the Germans secured a license to extend a line from eastern Brazil to the far northern boundary on the French Guiana border There are few inhabitants in that section and little or no trade The northern route offered opportunities for checking steamship movements in the Atlantic The Brazilian Government soon cancelled the charter for this line Between September 30, 1939 and September 30, 1941, the mileage of Axis lines in South America decreased from 25,700 to 14,480 On the other hand the lines owned and operated by United States interests increased in the same period from 18,460 to 33,520 In the autumn of 1941 not a single Axis line existed in Venezuela, Colombia, Ecuador, Peru, Bolivia and there was only one connection with Chile Some of the lines in Brazil had been taken over by the Brazilian Government Late in December all the German and Italian lines were grounded by the Brazilian Government. Services on these lines have been duplicated by government lines or subsidiaries of the Pan-American Airways. Even the Italian trans-oceanic operations have

been replaced by a new Pan-American Airways service across the South Atlantic to Lisbon No Axis plane flies within, or connects with, any portion of the Western Hemisphere

Blacklisting of Firms —Last year the United States Government discovered a considerable leak in essential war materials to the Axis in Europe through firms in Latin America For example, Germany obtained platinum from Colombia as late as early 1941 Likewise, as recent as late in 1941, Japan obtained block mica, a very strategic material, from Brazil and shipped it by air to her Axis partners Consequently, the United States has placed more than 4494 Axis firms in Latin America on a blacklist Almost without exception, Latin American countries have cooperated with the United States in enforcing the blacklist, despite the fact, that they are not legally required to recognize our regulations covering individuals and firms acting in the interests of Germany, Italy, and Japan

Freezing of Funds —Early in the war, in order to curb activities of the Axis agents, United States began to freeze the funds of occupied countries Last summer the United States froze all Japanese funds in this country Following the lead of the United States, most Latin American countries have frozen all funds of occupied nations and Axis powers Taken together, the freezing of funds and the blacklisting of firms has put the finishing touches on all German, Italian, and Japanese trade activities in the Americas as long as the war lasts

Trade in Raw Materials —Even more significant accomplishments have been achieved in the field of trade and sources of raw materials The British and American blockades have completely cut off markets which formerly took about half of the total exports of Latin America and regions which supplies essential manufactured goods The loss to Latin American nations in exports alone totals more than one half billion dollars Of course, the loss has not been equally felt throughout Latin America The Caribbean nations have suffered least because the United States has had a dominant position in their trade—both exports and imports Argentina and Uraguay have suffered most because their surplus agricultural products compete with our own At no time has the United States accounted for more than 15 per cent of the total trade of these two countries However, increased purchases by the United States have relieved considerably the financial distress in many sections, even to some extent in Argentina and Uruguay. In 1940, we purchased from Latin America one hundred fifty million dollars more than in 1938 In 1941, we purchased more than five hundred million dollars over the 1938 level. In other words, for Latin America as a whole our purchases have largely offset the loss of European and Asiatic markets.

Our increased purchases include many critical and strategic commodities The Metals Reserve Corporation, a government organization in Washington, has contracted to take all of the surplus copper, tin, vanadium, tungsten, bauxite, antimony, manganese, industrial diamonds, mica and other essential minerals In 1941, we purchased the entire wool clip and surplus accumulated stocks of wool in Argentina and Uruguay. The Latin American governments have cooperated with the United States by agreeing to deny all these essential war materials to the Axis powers and by pledging virtually their entire output to the war needs of the United Nations

The possibilities of Latin America in supplying essential war materials have only begun Of a list of about 40 materials essential to the production of military equipment, Latin American nations supply considerable quantities of 28 Among these are many of the critical and strategic minerals The output of these in Latin America can and is being increased rapidly. Shipping facilities will be made available to move these products to the factories of the United Nations Latin America can also supply large quantities of certain strategic fibers and other materials, such as wool, tanning materials, coconut shell char, and hides and skins On the other hand, we cannot look to Latin America to supply us with large quantities of certain products formerly almost entirely purchased in southeastern Asia Such things include jute, kapok, Manila hemp, quinine, silk, opium, and rubber Much has been written recently about the possibility of obtaining some of these materials from Latin America There is no production of jute, Manila hemp, silk, and opium in Latin America However, for some uses other fibers of Latin America may be substituted. Sufficient coconut trees are growing in Latin America to supply us with coconut shell char and also with a considerable fraction of our requirements for coconut oil. From the millions of wild kapok and cinchona trees growing in the tropical rain forests of Latin America, we can by the organization of a gathering industry obtain kapok fiber and quinine in considerable quantities. Despite rather optimistic estimates by several officials, the forests and plantations of Latin America cannot supply us

with sufficient rubber to make up for the loss of the supplies from Malaya and the Netherlands East Indies There are only two rubber plantations in Latin America. They can produce only a few thousand tons of rubber With time and much money for the organization of a gathering industry from the wild trees, we probably can obtain in 1943 about 60,000 tons of rubber from the wild rubber trees. This would be equivalent to less than 10 per cent of our requirements While many areas are suitable for the production of rubber on plantations, it would take at least six years, much capital, and careful organization to bring new large rubber plantations into production.

Even though we may obtain all that Latin America can produce of the above strategic and critical materials, we cannot get from those countries sufficient quantities for the manufacture of military equipment and at the same time supply normal civilian consumption However, by largely eliminating civilian consumption of many products, the United Nations can go a long ways toward obtaining from Latin America sufficient materials for the manufacture of military equipment Whether we like it or not civilians can and will for the duration get along without many commodities formerly consumed in large quantities This is true not only of the people of the United States but also those of the Latin American countries The realization by Latin Americans that the people of the United States will have to deny themselves of certain pleasures and luxuries has improved considerably inter-American relationships

Capital.—To obtain larger quantities of the above materials from Latin America will require much capital from the United States It is fairly well known that for a long time Latin American countries have not had the capital with which to develop their resources Even before the war, billions of foreign capital had entered Latin America While those nations have tapped various sources of revenue, most of them depend upon customs receipts for from one-third to two-thirds of their total government revenue Both imports and exports are taxed With the loss of foreign markets and with their inability to obtain imports, these sources of revenue have been cut drastically Consequently, in the present crisis the need for foreign capital in Latin America is greater than ever. Since the outbreak of the war, Germany, Italy, and all the occupied countries of Europe have been completely cut off as creditor nations. In order to prosecute the war, the United Kingdom has had to call in reserves of both private and government capital and credits in foreign countries. Consequently, the United States is the only large source of capital for Latin American enterprise and loans In September 1940, Congress allocated one half billion dollars to the Inter-American Bank for the development of Latin American resources and the orderly marketing of the products of those countries. Under these regulations, sizable loans have been made, one hundred ten million dollars to Argentina, three and one half million dollars to Paraguay and various sums between these two extremes to other areas Such capital is being used especially first, to develop facilities which will supply increasing quantities of strategic and critical materials, second, to improve transportation facilities, and third, to develop manufacturing establishments that can produce some of the wares formerly supplied by the continent of Europe

Though the recent loans and private investments and those that will be made may total hundreds of millions of dollars, they will represent a tiny fraction of the total cost of our war effort For the material and other aids Latin America can give to our war effort, this capital is well placed even though some of the principal may never return to the United States.

Military Aid —As a layman, I speak with less authority on questions of military matters than on economic Nevertheless, a layman with an economic and geographic training is in an excellent position to analyze certain phases of military defense in relation to problems of hemisphere solidarity and the war effort In the present world, no amount of economic and political planning can achieve hemisphere solidarity without the material equipment for exerting force—without adequate naval, army, and air power and suitable bases for their operations.

Latin American countries have not, until recently, seriously considered the possibility of military attack from Europe The Monroe Doctrine and the existence of the British and United States fleets have seemed to them adequate guarantee against that possibility The German conquest of most of Europe, however, with the resulting threat to the British fleet, the fact that the bulk of our fleet has been stationed in the Pacific, and the activities of German agents in certain South American countries have changed the picture, particularly for Brazil, Argentina, and Uruguay. These east coast countries face Africa, and could be threatened from there, should western Africa fall into the hands of the Axis partners. Northeastern Brazil, is only 1600 miles from western Africa.

This is only two-thirds of the distance from northeastern Brazil to Puerto Rico, formerly our nearest naval base

It is fairly well known that Latin American army and naval facilities are very limited Altogether Latin American nations have only 111 fighting ships, mostly average, with a total tonnage of approximately 263,000 There is no comparison between the size and equipment of their naval ships and ours The twelve Caribbean republics together have a naval tonnage of less than 19,000, less than that of one modern cruiser Yet the Caribbean area with the Panama Canal and Caribbean shipping lanes is a most strategic area Eighty-seven per cent of Latin America's naval tonnage is in Argentina, Chile, and Brazil—forty-two per cent in Argentina alone These southern republics have 5 battleships, 7 cruisers, 25 destroyers—with 9 more being built in Brazil—16 submarines, and many smaller vessels Furthermore, the armies of Latin America are small and poorly equipped

With these facts as a basis one might assume that Latin American nations could from a military point of view do little, if anything, to assist the United Nations As a matter of fact this assumption is far from correct After the attack on Pearl Harbor and the conference of ministers at Rio in January, nearly half of the Latin American countries declared war on the Axis powers, all except Argentina and Chile broke off diplomatic relations Breaking off diplomatic relations and a declaration of war means putting an end to all Axis propaganda and the arrest and internment of all Axis agents Most Latin American governments are doing a rather thorough job in this respect It means that the ports and naval bases of those countries are open to our merchant and naval vessels and closed to those of the Axis powers It makes available the small naval fleets for policing their own coastal waters. The Caribbean nations have gone one step farther They have permitted the United States to establish many airplane and other bases within their borders for patrol purposes for the protection of the Panama Canal and the Caribbean shipping lanes from marauding submarines Though the Latin American nations may not be able to give us great aid directly with their armies and navies, by an open break with the Axis, thus cutting off all intercourse with them, they may contribute greatly to the actual conduct of the war With the present position of Argentina and Chile, the American nations have not achieved complete hemisphere solidarity and complete cooperation in the war effort However, pressure is being and will be applied to those two countries until they fall in line with the other nations, thus presenting a solid front against the Axis

Conclusion —Most of the Latin American nations realize that economic and political security for them depends upon victory for the United Nations Because of the success of the Axis powers and the full realization of what the Axis program and Japanese Greater East Asia mean for conquered peoples, the Latin Americans are willingly working to aid the United Nations They realize fully that the job of supplying military equipment and fighting battles on many fronts falls heavily upon a few of the United Nations, especially the United States, the British Commonwealth of Nations, and the U S S R By supplying critical raw materials and by eliminating Axis contacts in those countries, the Latin Americans are giving valuable aid for the cause of democracy Despite minor differences of opinion, the people of the United States should give Latin Americans full credit for what they can and are doing in the war

III

"VS-300 HELICOPTER"

By Igor I. Sikorsky

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Many of us still remember the first decade of flying when planes were frequently operated from small fields, or even race tracks It was then expected that progress in the art would permit taking off and landing from still much smaller places Actually, the development went in the opposite direction and further progress made it necessary to use much larger and better airports than those which were adequate for the early airplanes This being the case, flying proved to be drifting away from homes, residences and places of occupation rather than moving towards them The possibility of an aircraft capable of duplicating the performance of a hummingbird that could land in any spot on the earth where it could spread its wings, appeared more difficult than was thought in the early years, even, perhaps, impossible It became evident, however, that while the fixed-wing airplane would never permit obtaining such performance, yet a good solution of the problem was entirely possible on the basis of a different principle of flying

The object of this article is to give a brief description of such a mechanical hummingbird, the United Aircraft VS-300 Helicopter, which is the result of a work that was started in 1909, was at times discontinued, then was resumed and finally resulted in the creation of the present aircraft This helicopter was completed in the Fall of 1939, it made many hundreds of small hops, underwent a large number of developmental changes and improvements, it demonstrated its capability for direct take-off and landing with no forward speed, as well as excellent flight and control characteristics Finally, on May 6th, 1941, the VS-300 established the world record for endurance for helicopters be remaining in the air for 1 hour, 32 minutes, 26 1 seconds exceeding thereby the previous world record held by Germany During this entire flight, it hovered above an area less than half an acre.

The success of the VS-300 leaves no doubt that the direct lift machine is here It might be interesting, therefore, to review briefly the type of service it can render

The helicopter in general must not be expected to replace or duplicate the service of the vast majority of military or commercial airplanes The helicopter's place in air travel is to solve a transportation problem that is not yet met by any other means While it will probably have a limited operating speed of between 100 and 150 miles per hour, yet due to its complete independence from airports, it will prove to be by far the fastest and often the best method of travel for the comparatively short distances that the average individual is usually called upon to go

For instance, it will cover the average 100-mile journey much more rapidly and more conveniently than any other vehicle of transportation, including its fixed-wing brothers It will do it more rapidly because the average journey is not from airport to airport, but from home or office to some practical destination In other words, a 100-mile trip in a 200-mile airplane would require, besides the 30 minutes of flying time, an average of from 30 to 40 minutes of ground transportation at either end, plus the often unexpected delays of making automobile connections, getting under way, facing traffic congestions, etc This being the case, the 200-mile-an-hour airplane becomes really valuable only for much longer distances, while for trips of 100 miles or less, the helicopter will prove to be much faster, as well as much more reliable and convenient

Darkness or poor visibility are an incomparably lesser danger or inconvenience to the helicopter than they are to the privately owned airplane. If the driver of a helicopter finds himself in a questionable predicament, he may slow down safely to 30, 15 or 5 miles per hour, just as he would in his car He may then proceed close to the ground, flying around obstructions or trees and, if necessary, he may land in any place the size of a 50-foot clearing The spot may be a vegetable garden, a ploughed or muddy field, or a rocky knoll, etc, and in all such places the helicopter would land safely and comfortably

The number of services that an aircraft with such characteristics could render can hardly be over-estimated In this tumultuous world, we must unhappily give thought to certain grim aspects In war, the helicopter will be excellent for communication, for sudden short range bombing

attacks, for convoy purposes both on land and on water, for observation, reconnaissance and scouting, for gun-fire control, for liaison behind the lines, for removing trapped or wounded troops, or for depositing troops behind the enemy lines, etc In government services it would be excellent for airmail over short distances, for carrying passengers and airmail between airports and the post-office or the heart of the city, for crop-dusting, for rescuing persons marooned by storm or flood, or delivering food and medical supplies to them, for coastal patrol and for life-saving under greatest possible variety of conditions

The facility with which the helicopter may render service under the most difficult circumstances is augmented by its ability to hover directly over one spot for indefinite periods of time Thus, even if a landing is prevented by heavy woods, surf or other conditions, a rope ladder or basket can easily be lowered to deliver or raise materials, as well as men

The above-mentioned performances are no longer a question of theoretical speculation because the possibilities of most of them have already been demonstrated with the present light, low-powered, purely experimental VS-300 helicopter. This aircraft has many times been taken off and landed on very small spaces, in backyards, often with some obstruction such as a big tree some 10 feet directly in front of the machine. Repeatedly a man standing on the ground has fastened a load to the end of a rope dangling from the helicopter while the ship hovered motionless above him It was then lifted into the air and unerringly deposited on a given spot or lowered into the arms of a waiting man Another demonstration of its ability is that it has often been flown up to a standing man while a suitcase has been placed on board, without the man taking so much as one step, and without the aircraft ever touching the ground.

From these facts, it may be concluded that a successful helicopter is now in existence and that it opens a vast and untouched field in flying It is now possible to look forward, earnestly and hopefully, to the rapid and final improvements that will bring this type of transportation to the world

IV

TECHNOLOGY AND HUMAN RELATIONS

By Carleton S Coon

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Introduction:

Never before, in human history, has a disturbance arisen as great as that of the present war—a disturbance affecting, directly or indirectly, almost every single human being on the face of the planet One of the automatic reactions to this disturbance has been the effort of political leaders, popular writers, and scientists to determine what is wrong with our system of world relations, that could permit such a disturbance to arise, and what can be done to make sure that it will not rise again, once the battle is won I assume that we shall, as we must, win it That is the premise upon which this discussion is based Some of the most far-seeing men of our time realize that we must solve this problem now, and not wait until the war is over, since its solution is as necessary for the shape of the war as it is for the shape of the peace to come

The principal difficulty, which has brought this state of affairs to pass, seems to be a lack of planning in human relations during the fabulous twenties and the twilight of the thirties Planning of this kind was more necessary then than it had been before, because, although few of us may have realized it, one era of history had ended, and another had begun People failed to realize how necessary it was to provide a basis for equilibrium for the lives of the different peoples of the earth, one which would permit an integration of the mutual relations of mankind as a whole

Before this time, technological advances could be made without upsetting the balance of the world, because the presence of empty land, or the conquest of technologically inferior peoples, allowed expansion without planning Once the empty lands had been filled, once the last of the primitives had been killed or packed off on reservations, the pioneering period was at an end, and it was necessary for us to make our adjustments within a contracting, rather than an expanding, universe. In the past we always made our expansions at the expense of simpler peoples, but we can do this no longer since there are no more such peoples to conquer or empty spaces to fill. Any expansion now is a case of dog eat dog

The only way in which adjustments can now be made is to abandon the age-old, automatic process of trial and error, and to plan them on the basis of the physiological needs of the individual human animal, and a recognition that these needs are the same, whether the animal in question is a modern American, an African Negro, or an Asiatic.

The equilibrium which we must attain is not to be defined in terms of economics alone, but rather in terms of the way in which people get along with one another One of our greatest mistakes has been to leave the process of adjustment in the hands of the economists and engineers, who, however expert they may be in their own fields, have only a lay knowledge of human relations. They are therefore unable to see the human consequences of the changes that they have themselves instituted. They should not, however, be blamed for this, since they have done their own job remarkably well, the error lies in their belief that because they could build automobiles or float international loans, they were experts in human relations as well.

The results of this fallacy speak for themselves Every plan, whether for a new world order or for a Treaty of Versailles or for a League of Nations, has to be run by human beings Its operation involves the emotions of human beings, and their peculiar ways of behaving No plan works automatically The usual excuse of the people who tackle these problems in terms of economic or political logic is that they regard human nature, as it manifests itself in human relations, as an extraneous factor over which there is no control, and which spoils the beautiful symmetries of their cloud castles They say "It was all politics," or "it was ruined by graft," not realizing that politics and graft are predictable phenomena of human relations.

The only test of a plan is to see whether or not it works The excuses made by planners of world orders that did not work, and by unsuccessful international politicians, are as fallacious and self-incriminating as it would be if an engineer, when his bridge collapsed, were to say. "It was a beautifully designed structure, but one can never tell

about the strength of metals" Builders of world orders must find out about the properties of human beings in their relations to one another, and this can only be done if we start at the beginning and study the physiological basis of human behavior

The Physiology of Human Relations.

Human relations, as students are beginning to realize, form an essential part of the activity of the human organism, and cannot be separated from this activity any more than the "mind" can be separated from the body Each human organism, like other animals, maintains what is called an internal equilibrium, essentially similar to the equilibrium of inorganic substances long recognized by the physicists and chemists This equilibrium is maintained, as long as the organism is alive, through a series of bodily processes, changes in the rates of which we call *emotions* Emotions may be defined as disturbances in the equilibrium of the bodily processes which are produced by changes in the external environment They are, in other words, the reactions which occur when these bodily processes try to adjust to new conditions

Cannon, Bard and others have shown how what is called emotion is made up of the combined effect of changes in heart activity and respiration rates, and in the velocity of the chemical secretion of blood sugar, adrenalin, mecholyl, and other substances These adjustments are regulated by the autonomic nervous system, which is consequently responsible for maintaining equilibrium when sudden changes take place in the environment, which disturbs the equilibrium, rage and fear responses are set in operation

These emotional patterns are basically reflex in character Though we learn to discriminate between stimuli, that is, though we become conditioned by experience, some reaction always occurs in response to changes in stimuli If these changes are sudden, that is, if we become afraid or angry, cortical control is decreased, and our capacity for adjustment, for fine discrimination, and for carrying out our regular routines, is lost

In any institution, that is, a family, political group, industrial organization, etc, changes in stimuli are constantly activating the autonomic nervous system and its associated organs of the individuals concerned These stimuli, affecting each individual, come primarily from other people, and our relationships with people are consequently the principal source of our emotional experiences These relationships take for the most part the form of routines, to which we become conditioned, and when these routines are interrupted we suffer emotional disturbances That is why it is so difficult to get people to change their habits in an emergency which has not already affected them personally

If the contacts which we have with other people and to which we are conditioned occur with a regular frequency, or if the changes which take place in them are quantitatively small enough so that rapid adjustments can be made, the autonomic nervous system maintains the organism in a state of equilibrium If sudden changes, to which we cannot readily adjust, occur constantly, if equilibrium is not rapidly restored, then the autonomic balance is upset and marked compensatory changes in activity take place Then the system of relations is upset, people are frightened and angry, they are unable to adjust to others and to accomplish tasks which require cortical control. In other words, they lose their heads And when they lose their heads they do things that will serve to upset the equilibrium of the people with whom they are in contact, and these people may in turn disturb others, until the equilibrium of large institutions may be disturbed

The problem of equilibrium in a state is essentially the same as that of peace in the family or morale in an industry In each case the problem is to organize the technical routines of operation, be they family routines, or political, or technological, in such a way that the equilibrium of individuals is maintained, or, if once disturbed, is rapidly restored before the violent compensatory reaction of fear and rage take place In simpler words, a state of peace, equilibrium, morale, or whatever you wish to call it is obtained when the individuals within groups can adjust rapidly to changes without becoming afraid or angry or both

Since the technical requirements of the work or duties of any institution, be it a family, a state, an industrial plant, or whatever, require certain daily, weekly, and other routines, and since the individuals who perform these routines have to learn complex motor habits, the aim of any planning board, or management, whether it be for a button factory or a new world order, which wants to succeed, must be to see that these routine habits can be carried out in times of crisis as well as under normal conditions This can be done, but only if the individuals of whom the family, the factory, or the world order is composed are not constantly disturbed and emotionally upset That is why free men work better than slaves, and why a state founded upon justice, equality, and a voice for all

is, in the long run, a more lasting and progressive state than one founded on tyranny

Technology and Human Relations

It is readily apparent, therefore, that the requirements of the human organism for equilibrium in interaction, which may be called "human nature," are more or less constant, and that in all populations they will vary individually within more or less the same limits In every population there will be some who are energetic and others who are not; some with the capacity of leadership and others who lack it Furthermore, as far as we can tell at present, the inherent capacity of the individual for making cortical linkages, which seems to be the basic variable in what we refer to as intelligence, also varies in each population within given limits, and differences in so-called intellectual performance between groups of people may be attributed not to genetic differences but to differences of conditioning

In view, therefore, of the essential equality of mankind, one is led to ask what is the reason for differences in the complexity of human relations in different societies, why are some people "primitive" and others "civilized," and what bearing has this problem on our problem of establishing a world equilibrium? The answers to these questions are that variations in the complexity of human relations depend on differences in the technological processes by which people exploit their several environments, since the bulk of human interaction, i e human relations, is carried out on a technological framework For that reason the understanding of technology is essential to the problem of planning a world equilibrium

A few examples should suffice to show how technology, in combination with environment, controls human relations Let us first consider the technique of water transport Two French Canadian trappers are paddling downstream in the early summer, from their trapping grounds to the trading post, with a heavy load of furs One man paddles bow, the other stern, their actions must be synchronized if they are to reach their destination. Thus the technique of canoe paddling determines their mutual relations during the working day in summer, but it determines a number of other things as well. It limits the number of men who can work together at this enterprise, it limits the amount of fur which they can bring down, and the amount of food and other supplies which they can take back in the fall In combination with their other techniques it limits their relationships with other people, making it impossible for them to take their wives and children along, enforcing isolation on the two of them during the long winter, limiting their interaction with the trading company to a brief period, and their participation in state and church to the same time Men who live by this and the accompanying techniques cannot build up complex sets of human relations

Another example may be drawn from the field of manufacturing In the mountains of Morocco, in the tribe of Taghzuth, the land is too poor to support a large population Nevertheless there is a large supply of tan bark in the forests The men of this tribe are mostly craftsmen, and many of them are engaged in tanning hides and manufacturing leather bags to be sold outside In some instances a man and his sons run a leather-working establishment, and the pursuit of this technique enforces the frequency of events within this segment of a family The need of buying hides and selling the finished product establishes other relationships with specific individuals In times when the demand for leather bags is great, the master craftsman will hire apprentices from outside the family, which will mean new relationships, and he may delegate to one of his sons or apprentices the task of selling the bags to jobbers, so that his commercial relationships are thus extended and canalized

If the average American will consider the techniques which he himself practices, be they metallurgy, medicine, pedagogy, or whatever, he can readily see how his own human relations are determined by them, and how this extends to his relations outside his immediate technical pursuit, as for example to his family He gets up in the morning, and after interacting briefly over the breakfast table with his wife and children, runs for the train During the day his time is taken up with relations in other institutions, in which he has been conditioned to a daily routine, if that routine is seriously disturbed he will have had a "bad" day He meets and must adjust to dozens of persons in different institutions during the day. This wide range is facilitated by his use of the telephone, the automobile, the subway, etc. The more complex technology of his civilization renders his daily routine of interaction correspondingly more complex than that of the fur trapper or of the Taghzuthi leather worker.

Equilibrium in Technological Processes

In any technical process in which a number of people work together, be it in government, the

church, industry, or the family, there are three potential sources of disturbance, as follows The first is *the inefficient definition and allocation of work*, in which people do not know exactly what they are supposed to do, or what is the most efficient way of doing it Such technical inefficiencies prevent individuals from making satisfactory relations to one another in terms of the work process They are unable to develop regular work routines and are constantly upset

The second is *the maladjustment of personalities in terms of the work process*, where individuals with personalities which they cannot adjust to one another are forced to work together by the requirements of the job For example, the two fur-trappers who are paddling their canoe must be similar in activity rates, so that they can paddle together synchronously Otherwise they would become upset, and angry at each other, and their partnership would dissolve The only way to avoid difficulties of this kind is to get the right man for each job, and this can best be done by an objective study of the physiological properties of the individuals concerned, in terms of the specific job A military leader, excellent at organization in peace time, might be useless on the field of battle A McClellan will not make a MacArthur.

The third is *faulty relations between members of different organizations*, as when the heads of the Army and Navy will not speak to each other and thus permit a military disaster, when the members of neighboring countries cannot understand each other and hence develop friction whenever they meet, when the superintendents of factories leave everything to their overseers and have no contact whatever with their men, and many other such examples

Disturbances of all three kinds can be avoided or eliminated if we understand not only the technological processes concerned, but also the biological properties of the people who practice the techniques. A technique exists only as some human being or group of human beings practice it You cannot talk of a technique as apart from human relations, as some archaeologists discuss potsherds and bronze axes as if they were living organisms that procreated and evolved without the aid of man, the archaeologist who works in these terms will never make a true reconstruction of history, and the planner, political, industrial, or otherwise, who plans in terms of treaties, bank-notes, or machines without thinking of the men whose relations are determined by these devices will never plan a working society.

Modern Technological Systems:

As we have already stated in the introduction to this symposium, the technological systems of what we may call the colonial or pioneering period in our world history are in the process of replacement These technological systems were characterized by methods of communication vastly inferior to our own, so that no world equilibrium had yet developed. The world of mankind was broken up into a series of isolated or nearly isolated systems For example, the United States obtained rubber and rattan from the Malay Peninsula, but the natives of these two countries seldom saw each other and knew little about each other The same was true of the relations between Argentine beef-growers and the Englishmen who ate the beef, etc

Within the major systems, by which term we categorize the great, imperialistic powers, the adjustment of individuals was unstable, and equilibrium was attained only through external aggression The mill-workers of Lancashire could be kept at their looms only as long as British soldiers and merchants carved out new markets for their cotton fabrics in Africa and Asia, and later on Japanese industry was dependent upon Japanese shipping and trade

Sooner or later, as the frontiers disappeared, these major systems were bound to come into conflict with one another, and since each of them could continue to maintain its former type of equilibrium only by further expansion, the expansion of one would necessitate destruction of others This process of expansion and conflict has been accelerated by the rapid improvement, during the last two decades, of our techniques of travel and communication, in combination with an increasing efficiency in manufacturing processes, particularly in the field of mass production We are no longer concerned with partly isolated systems whose relations are carried on at a low frequency in a few channels only After the last war England, France, Germany, Japan, Russia, and the United States had the choice between a mutual adjustment or an explosion Attempts at adjustment failed because of their unwillingness to consider the human requirements of everyone concerned

Inequality in material possessions is characteristic of intermediate stages of technological development. The simplest food gatherers, like the Australian aborigines, are all equal—each man has his flint knife and his handful of spears, each woman her digging stick and her stone for grinding seeds; they could not own more things than these because they could not carry them about

with them in their search for food With sedentary life and improved techniques, the relatively complex relationships which arise between individuals in societies produce the basis for inequality We are still in an intermediate stage in this respect, but we have made the technological advances which will inevitably bring us out of it, to a third stage in which the distribution of goods can once more be approximately equal In other words, we have now attained the position in which we can calculate the requirements of our populations and we can look forward to their fulfillment

These requirements are not concerned with bodily comfort alone, but also with the techniques by which people can adjust to one another most successfully The widespread use of the automobile in the United States will serve as an illustration. Efficient transportation enables us to avoid a rigid system of routines, conditioned by life in a small circle of relationships, it enables us to interact in a wider and more varied circle We can choose the friends of our liking from many communities, instead of having to get along with our immediate neighbors, whether they are compatible with us or not We can move out of the cities and adopt routines more satisfactory to those who cannot adjust easily to crowded urban life The possibility of cheap airplanes or helicopters in the near future means that this process may be extended even further It may not be too rash a generalization to make that nations whose peoples are relatively mobile, from the Arabs and Mongols to the modern Americans, have a greater flexibility of adjustment and hence a greater stability, than purely sedentary peasant and urban communities

It is not only in the field of transportation that modern technological science has provided us with new developments, even since our entry into the war Great advances have also been made in mineral extraction, metallurgy, and other basic techniques, so that the technological basis for human relations has been potentially extended to an enormous degree, this means that it is now possible, or that it will be when the war is won, to maintain constant relations between people in all parts of the earth, that our problem of timing in world events can be solved, because the technical means are at hand Once people can be made to realize the significance of these changes and reconditioned from their habitual patterns of behavior, technology has provided and will increasingly provide for that ultimate stage in human democracy, when the peoples of the earth will share alike in its products, and hence differences in their relations to each other will depend upon differences not in race or place of birth or wealth, but in individual personality and attainment

If, therefore, we plan wisely, and if we strike in time, our conquest of technology should, even in our own lifetimes, bring to the world what we now fight for—universal freedom—that equality of opportunity for all the peoples of the world which we in this country have been promised and have of all peoples most nearly attained

V

THE NATURE OF WORLD EQUILIBRIUM

By Conrad M Arensberg

Introduction

Now that we have seen how technology, acting upon the human organism, conditions the form and extent of human relations, our next task is to determine what structural form these relations take, in other words, how individuals adjust their personalities to each other in institutions

The importance of technical activities, is not confined to the direct conditioning of the relations of specific individuals Technology has even broader implications, it controls the ways in which groups of individuals live and work together The requirements for interaction which it imposes necessitate the mutual adjustment of groups of individuals in such a way that they attain a state of equilibrium

We have already seen how the physiological properties of the individual himself bring about such a state, but in order for any kind of stability to be maintained, all the individuals with whom he interacts must also achieve a similar state and this can only occur if the relations of all individuals together form a system in equilibrium

In the performance of any technical activity, where more than a single individual is involved, an adjustment must be developed between the individuals concerned In the case of the French-Canadian trappers mentioned in the last paper, an adjustment between the two individuals concerned had to occur or else the pair would have been unable to work together and would have had to split up In more complex technical activities, however, where a number of people have to interact in order to accomplish successfully their technical end, one of the individuals must act so as to secure some degree of coordination between the several persons and the tasks to be performed, if the activity is not to fail completely

For example, in a Paiute antelope hunt observed in Nevada almost a hundred years ago, the Indians had built a corral of logs at the end of a valley, and had placed clumps of sagebrush in two diverging lines from the mouth of the corral for several miles up the valley At the appointed time several hundred Indians were stationed at fixed points, some between the clumps and others up on the hills When the signal was given the men on the hills started beating and yelling and driving all the animals in their neighborhood down the slope, as the animals tried to dart between the clumps of sage-brush, other Indians would jump up and frighten them back, until finally all or almost all of the antelopes, jackrabbits, and other animals had reached the gate of the corral, where the men converged and drove them in

This antelope hunt required the cooperation of many people, under the direction of a leader, who organized the hunt in the first place, bringing people together from their distant camps, telling each of them where his station was to be and what he should do, and giving the signal to begin

In our own society we can take almost any example to illustrate this One of the easiest to illustrate is that of a ship, even on the smallest tramp the technical requirements of operation make it necessary for many men to perform different skilled tasks at the same time, or in ordered sequence When the ship is about to leave the dock many things happen at once The donkey men draw in the loading booms, the stevedores march ashore over the gang plank, and members of the deck crew batten the hatches Down below the chief engineer is watching his dials while the black gang is feeding the furnace, and the oilers are at their stations along the main shaft Up in the chart room the mate is plotting a course, while the captain talks to the pilot, who has just come aboard The time has come to shove off The captain pulls the lanyard for the ship's whistle, and the men below take their positions on the deck The captain signals to the bos'un, who blows his whistle Members of the crew draw in the gangplank, and the men standing on the pier cast off the bow lines Then the donkeymen reel these lines in quickly A bell rings, the captain has signalled to the engineer—the propellor turns and the ship moves forward and outward Now the stern lines are taut, and the propellor churns the water; the ship is thus turned so that its axis lies at an angle to the dock Another signal, and the ship moves astern, the stern lines slacken and are cast off. Now the ship moves forward and steams away from the dock and out of the harbor

In this familiar scene of a ship leaving port we have an example of a sequence of events involving a number of men who perform separate, specialized tasks in such a way and with such accurate timing that a complex maneuver is executed In this

instance and in that of the antelope hunt, the successful accomplishment of these separate duties in unison can only occur if some one individual's actions serve as the signal for others to perform their parts of the operation Events such as these occur continually in daily life, and their repetition conditions individuals to the performance of specific technical activities under the direction of specific leaders These recurrent patterns of ordered action make up the structure of society These routines are physiological in nature and provide the individual with the basis for his equilibrium When these routines go wrong, as when the antelope break through the line of beaters or the ship fouls the pier, rapid changes occur in the activity rates of the individuals concerned, and the resultant emotional disturbances can readily be seen

The Division of Labor and the Complexity of Institutions

In all human societies there is some kind of a division of labor which the specialization of the men on shipboard will illustrate It derives not merely from the fact that many techniques in fact require several individuals to perform them, but also that individuals have different capacities to perform different types of work The simplest example of this differentiation, which is found in all societies regardless of their technological level, is the division of labor on the basis of age and sex Thus men hunt, fish, trade, and go on the warpath, while women take care of the children and do their housework, children play, adults work, and senile individuals reminisce with each other while basking in the sun

But within this general division, individuals tend to specialize, one man spends most of his time trading, and another at making weapons for the rest of the group, one woman concentrates on making pots, while another may weave blankets for which she is specially noted This part-time specialization, due to the special aptitudes of the individual, derives largely from the essential physiological properties of human beings, in terms of the technical differentiation which these simple tasks necessitate

As people develop more and more complex techniques, a further division of labor takes place In weaving, for example, instead of the whole process being performed by one person, from shearing the wool to the final process of dyeing, several persons may specialize, one to shear, one to spin, one to weave and one to dye the finished material. Since a specialist is more skillful than a jack-of-all-trades and can, with superior techniques, produce more goods per day or per hour, people who live on such a level have more material possessions than those who lack this kind of division of labor

As the techniques become increasingly complex, an increase in the division of labor is not the only result, another is the need for more and more supervision In an automobile factory there is a whole staff of men whose task it is to plan operations and to organize the workmen, as well as to direct them, leadership becomes increasingly elaborate and itself specialized

In any group of men working together at a task of any complexity, therefore, there must be organization if the task is to be successfully done This organization must be habitual—that is, the man who is leader one day must also lead the next, and the order of action from director to foremen to workmen, and from department to department, must be habitual and the personnel must be suited by their personalities to their several roles, and conditioned to them as well

The Organization of Peasant and Urban Communities in the Pre-war World

Now that we have seen how the complexity of institutions of which societies are composed depends upon the interactional requirements of the technology available to the group, we can begin to estimate what effects the systems existing before the rise of the modern technological age will have on a world order Even today new and old technical systems face each other throughout the world, and the attainment of a world equilibrium is dependent upon the way in which these adjustments are made

We can leave out the extremely simple, primitive societies, such as those of the Australian Aborigines or Eskimo, which numerically speaking are of little importance, and concentrate our attention upon these groups of people whose principal technological pursuits are agriculture and manufacturing

Aside from these primitives, then, the pre-war world could be roughly divided between communities which we can label by the term peasant, and those which participated fully in the advanced technology of the late nineteenth and early twentieth centuries. A good example of such a peasant culture is to be found among the farmers and fishermen of Western Ireland Here the most important institution is the family, and the agricultural techniques by which people make their liv-

ings are all carried on within the membership of this limited circle. This agricultural system, based upon the family, was tributary to the urban system of the British Empire, since the grain and beef cattle which the Irish peasants produced as their cash crops flowed mostly to the markets of industrial England

This Irish peasant culture, with its emphasis on the practice of agricultural techniques within the family, has changed little since pre-Christian times The Kings of Tara, the Anglo-Norman overlords, the British territorial governors, and the Irish Free State government itself, mark successive changes in the political organization of the country, and the language of the people has even changed, without this family system being visibly altered The reason for this conservatism has been that whatever the shifts of authority at the top of the political organization, whatever the changes in the lives of the rulers, the peasants themselves have continued to till their fields with the same kinds of tools and in the same ways and have thus undergone no visible change in basic technology Since the relations of people depend on their roles in practicing techniques, the typical Irish peasant system has survived unaltered

What is true of the Western Irish is true in general of peasant communities everywhere, in Russia the liberation of the serfs and the assassination of the Czar made little difference in human relations in the countryside, because the farmers were still using the same plows and the same rakes and fattening their pigs in the same way Changes in the structure of Russian peasant society did not come with communism, but with the introduction of the tractor, just as what little change has taken place in modern Irish peasant communities in recent times is associated with the electric butter churn and other such devices

To these peasant communities may be contrasted the urban civilization of the period in question Each European country and many countries in other continents, had a number of cities in which people lived with enormously greater specialization and division of labor, and in which they practiced much more complex techniques than their country brethren In urban centers people worked in factories and other large enterprises and exchanged their manufactured products for the foodstuffs and other raw materials of the countryside

Nevertheless the relationships between urban and rural communities were limited to a few channels The peasants bought their goods at the cross-roads store or from pedlars, but they seldom saw or talked with the people who made these objects; they remained in their rural environment and maintained their rural system of relationships in almost complete isolation This is exactly the same situation which obtained between the nations which were largely urban, such as Great Britain and the Netherlands, and the colonial regions from which they drew their raw materials, such as the Malay Peninsula and the Dutch East Indies The lives of the natives in these latter regions were relatively unaffected by their relations with the industrial nations, although they bought ready-made cloth for their clothing and rode bicycles, the basic techniques by which they raised their food and got along with their fellow men remained the same

The reason why urban and peasant communities throughout the world remained relatively isolated during this period, can be found in the field of transportation England could ship goods around the world in her merchant steamers, but they put into relatively few ports, and the distribution system on land was, except for the railroads, little better than that which existed in Roman times The railroads themselves were costly to build and operate and could reach directly only a small proportion of the peasant and colonial populations

Another branch of technology which was partly responsible for this situation is the field of communication Without telephone or radio, relying entirely upon the rails and the telegraph, events could occur weeks before administrators in the capitals of world empire know about them, and what is more important, peasant populations could remain largely isolated from any administrative action

As I pointed out in the case of Ireland, the peasant societies throughout the world achieved a state of equilibrium which remained relatively constant over a long period of time Within the cities, as a function of changes in technology, there was a continual struggle for dominance among the various economic institutions, as each group tried to achieve an equilibrium for its members in the face of competing institutions This attempt of technological systems to stabilize their relations with customers and sources of supply was carried over into a contest for control of the political system Yet whichever group temporarily seized control, the life of the peasants went on with little change

The very stability of these peasant systems and their isolation from the urban centers and administrative officers of the government made the oc-

casional efforts of the latter to introduce changes of little avail In fact, changes in the relations of peasants and overlords brought about automatic reactions within the peasant community, and thence reactions in turn produced a restoration of equilibrium Thus when the overlord overtaxed the peasants, the latter became angry and banded together to resist the tax gatherers. The overlord could destroy the community but he could not change its rate of production or its level of equilibrium

Modern Technology and the Equilibrium of Institutions ·

The technology of the present period is rapidly destroying the contrast between rural and urban systems of relations, and that which has existed between imperialist nations and their colonial dependents The reason for this is not hard to discover In this country, which pioneered in the modern technology, country people and city people use the same technical devices for many of their operations; they both use electric washing machines, electric flat-irons, etc They both ride in automobiles, and furthermore they can see the same moving pictures, listen to the same radio programs, and read the same magazines With improved transportation people who work in the city can now live in the country, and people who work in the country can make frequent trips to the city Many factories are now built in the country, and draw on rural populations for their labor

Thus the influence of present-day technology is to bring country and city people into a single major system of relations which must achieve an equilibrium We have no longer a peasant backlog, maintaining an even subsistence level in bad times and good, always able to eat but little more, today the farmer of the dust bowl is just as subject to profound fluctuations as the factory worker or the shipper All of us in this country are part of a technological system based upon mass production

In outlining the general framework for a world equilibrium, therefore, we must reckon with the fact that the changing nature of our technological system and the changes in human relations which it is bringing about are proceeding at differential rates in different countries Attempts to organize a world system must take into consideration the fact that the necessary changes in human relations can be introduced only through the sphere of technology, and that these changes will of necessity be incorporated within the existing organizations in the different regions of the world In so doing, however, the equilibrium will be disturbed, and if the change required is too great, a period of instability will result before a new equilibrium will appear In order that this can be done most effectively, the changes must be made within the framework of existing regional systems These must be granted local initiative and local autonomy, necessary for the successful operation of the larger organization by which the world technology can be stabilized

Conclusion

The technological changes by which man can be emancipated from too great a dependence upon nature and which will necessarily occur unless the world goes completely to wrack and ruin can cause at the time of their introduction relatively great or little harm If they are put into operation without regard for the necessities of the systems already operating, contrary to the organization of the institutions which have already been worked out among the people concerned, then serious compensatory reactions will take place If however an attempt is made to determine what the ordered interactions of the individuals actually are, the techniques can be introduced in such a way that the system is only momentarily disturbed, and can easily achieve a new state of equilibrium If this is done, and to do so requires careful planning on the local level, we can look forward to the time when a world equilibrium will have become as habitual and as stable as the peasant communities of the past Unlike these, however, they will provide a free system within which every individual can achieve an equilibrium and an effective adjustment to his world

VI

HOW A WORLD EQUILIBRIUM CAN BE ORGANIZED AND ADMINISTERED

By Eliot D Chapple

Presented March 11, 1942

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Introduction.

How can a world equilibrium be organized and administered? Any answer we choose to give to such a question can by necessity be only a partial one. Yet answer it we must if we are to survive, and our hopes of success will be immeasurably strengthened if we base our plans on the principles of human relations

We have to begin with human beings, and with human beings who have already been conditioned to habitual routines of interaction You have heard something of the constraints which these routines will impose upon any world system, and of the modifications and limitations upon our relations to others which we can expect from our present-day technology Any plan for the organization of a world equilibrium must be based upon these operating realities

Equally important in planning an organization, however, are the steps by which one's plans are put into effect, for these steps determine the form of the plan which results Unless all the combatants disintegrate through exhaustion, the end of the war will be a military victory, followed by military occupation of the conquered countries An organizational plan must, therefore, take into consideration the basic fact that a military occupation with military governors, martial law, and emergency measures must be transformed into an effective political system This transformation must be carefully planned—the automatic tendencies of systems of human relations to return to a state of equilibrium must be guided within calculated channels Otherwise, armies of occupation will tend to become permanent and will then be rationalized as a preparatory and educational interlude for a political adulthood which will never come In the frantic haste of victory, the carpetbagger, whether the simple exploiter of our Civil War days or the more sophisticated Commission used after World War I, often seems to be the only means by which political order can be restored As history has shown, such reconstruction methods can never bring about a restoration of local autonomy within the framework of a centralized control which will achieve equilibrium Carpetbaggers of every form and carpetbagging policies towards the vanquished act as disturbing forces on the system, bringing about violent compensatory reactions on the part of the governed

We cannot hope, therefore, to implement the Atlantic Charter and bring about a world equilibrium, unless these facts are realized We must learn the bitter lesson, that we have to plan for human beings, and not for "economic men" or "political animals" or "men of good will" We have to plan, in other words, according to the ways in which people actually do behave, and not as we think they ought to behave And our plans must contain the steps by which they are to be put into operation, steps which must be taken at the moment of military victory, and not delayed for some more propitious future which will never come

The Relative Efficiency of Totalitarian and Democratic Systems

Changes in the interaction rates of individuals are the disturbing forces in systems of human relations When such changes occur, the equilibrium is upset, and the changes in the autonomic nervous system which result include compensatory changes in the interaction rates In our ordinary experience, we recognize emotion by such changes, and we recognize too the necessity for the individual to blow off steam, to complain about the injustice done him, and to seek redress and thus, in more precise terms, to reestablish his state of equilibrium

We have already discussed how the technical activities of every day life provide the context within which interaction takes place, and in which individuals adjust to others, or become seriously maladjusted The organizational structure of every institution is built up on routine events in which one person acts and a group responds, and through which the technical activities can be performed at given frequencies and in habitual ways When disturbances occur in the adjustments of individuals, compensatory reactions take place within their habitual relations to others If these reactions alleviate the disturbance, equilibrium is restored The efficient organization or system is that in which these reactions produce adjustments within the system rapidly and along well-defined channels

In designing the plans by which effective organizations are set up, planning experts have already worked out many procedures which, if properly

applied, can help the officers of administration to maintain a stable state within their organization, and to eliminate disturbances rapidly In general, however the administrators use even these procedures to a limited extent only, in fact they usually apply them only to the upper brackets of the administrative hierarchy, and rarely consider the needs of those on the lower rungs Thus they fail to take into consideration the essential unity of the system and its need to be treated as a whole

The result is that most compensatory reactions run down the line of authority, and each administrator restores his own equilibrium, when disturbed by a higher-up, by acting upon his subordinates At the bottom level, there is no ordered channel, the governed have only each other as outlets In such an organizational system, which we have recently come to call totalitarian, there is no provision for modification of administrative action except by direct appeal up the line, and such an action brings about a compensatory reaction in the opposite direction Where disturbances occur with any frequency, the flow of actions down the line requires the individuals at the bottom to be highly conditioned so as to respond automatically to the actions of the hierarchy Each such individual can find compensatory outlets only in persons upon whom he is permitted or encouraged to act—his wife and his children, members of outcast groups, and members of other nations A totalitarian system, therefore, prevents any modification of the structure from below, in response to changes in environmental and technological conditions Yet it is on the bottom level that such changes are continually occurring If the disturbances passing down the line are too frequent and their intensity becomes too great, the necessary result is conflict; where possible, rebellion, where not, non-cooperation, restriction of output, sabotage, and an increasing incidence of mental disorders

Even though systems of this kind have operated for brief periods in the past in different countries, they are necessarily unstable, and in times of technological crises, subject to automatic and violent compensatory reactions Under present conditions, it is highly doubtful that such systems can be as effective as was formerly possible In peasant communities, the administrative hierarchy operated at a much lower frequency due to the low interactional requirements of the agricultural methods then in use It was therefore possible for such a group to maintain its equilibrium even under a totalitarian regime by virtue of becoming a self-contained, highly isolated system with its relations to the outside world cut to a minimum

Our modern mass-production technology depends not only upon the complex interrelations of countless individuals within the manufacturing institutions; it also depends upon mass-consumption The administrative hierarchies necessary to make such a system work operate at a high frequency, an assembly line cannot be run by absentee foremen The complex adjustments of individuals within such a system which must occur if it is to attain a state of equilibrium cannot take place if the individuals are emotionally disturbed—a necessary result of totalitarian conditions in times of peace. When war is over, and a world-hegemony has been reached, aggression on individuals external to the system no longer provides any kind of outlet Unless actual outlets within the system are provided, no equilibrium is in fact possible

As an alternative to the so-called totalitarian system, there has been devised the democratic or representative system, in which the people at the bottom of the administrative hierarchy are able to act upon the administrators As everyone knows, the representative system is one in which I, the governed person, the man in the street, am able to compensate for a disturbance to my equilibrium by acting upon my representative, whom I choose, who in turn is able to act upon the administrator, in order to bring about changes in *his* behavior which will restore my equilibrium It is a circular system in which the compensatory mechanisms are part of the organizational structure

The democratic system is merely a representative system in which all of the administered who are adults are members of the class of those who are acted upon, and who in turn act upon their chosen representatives The degree to which this system is effective in maintaining a system in equilibrium is a quantitative problem, whether in fact a system can be called democratic is again a question of quantity In many countries it became, the fashion, at one time or another, to set up such a representative system, and the unwary who looked at the form and not at the working system of human relations spoke of such countries as democratic The facts of the case were that they were merely disguised totalitarian systems, set up to make the people think that they had a voice in the government, and thus to lull them into a state of equilibrium Since the representatives chosen by the people had no power, and the actions of the people upon these men produced no results, this ruse served only temporarily to alleviate the

disturbance of the individual citizens The fact that the representatives could bring no change in the administration meant that the circular system was not in operation, hence the governed obtained no modification of the administrative policy, and the basic disturbances inherent to such a system soon returned. In this country, a similar situation existed in the so-called company unions or employee representation plans formerly the vogue in industry, when, as was true in all except rare cases, the employees found that they had no opportunity of acting on any matters which were of real importance to them, they soon lost interest and sought compensatory outlets elsewhere

If we are to organize a world equilibrium, we will tend towards one or the other of these two solutions of the problem We may obtain the totalitarian solution in fact, while having the democratic solution in theory In our opinion, the most efficient system of organization in terms of the realities of human relations, is the democratic one It provides habitual channels within which compensatory reactions may operate to restore the equilibrium of the system It enables one to introduce technological changes without running too much risk of causing severe disturbances of which the administrators became aware too late It is the only method by which large scale organizations can be run efficiently And it provides for a retention of local autonomy and local initiative within a world-wide order The criticisms so frequently made of the inefficiency of democratic systems as compared to the totalitarian are due not to the fact of having too much democracy but of having too little Inefficient organization is the result either of the failure to use present-day knowledge of organizational principles in setting up the organization, or of the existence within the government of a totalitarian sub-system which is successfully able to short-circuit all attempts to bring about changes in its administrative procedures A brief examination of actual cases drawn from history will indicate to anyone that such inefficiency, with rare and temporary exceptions, is most characteristic of totalitarian regimes

The Organization of a World Equilibrium ·

If the democratic system provides the most efficient way we know of organizing a world equilibrium, the problem is, how can such a system actually be put into operation on a world-wide basis? The previous speakers have sketched for you something of the materials with which we have to work; it is my task to outline the general framework of a system of organization in which major sources of disturbance will be eliminated

You have already heard how important a part technological routines play in determining the interaction of individuals The greater part of every individual's day is spent in technical activities, and the complex interdependence of individuals produced by our present technology has brought about the formation of regional systems, throughout the world, each of which can attain a stable state of equilibrium For this reason, in outlining the basis for organization of a United States of the World, each state which forms an administrative unit must not be an ethnic or linguistic group, or even a nationality, it must be a natural geographic-technological region, within which trade and the exploitation of natural resources occurs within the bounds set by natural barriers, climate, and the common highways of travel, regardless of race, language, or ethnic identity Examples of such areas are the Danube Valley, the Mediterranean, the coasts of the Baltic and the North Seas, and so on I shall not attempt to list all these unit regions or to set their boundaries The exact limits for each area can only be fixed by determining whether or not the frequencies of interaction occurring within the technological institutions of a given area possess the properties of a system in equilibrium

A word perhaps ought to be said to explain why we regard nationality, ethnicity, language, and also religion as unimportant in the formation of these natural geographic-technological regions The organizing principle which we have followed is to select those conditioned routines which bring about the greatest amount of interaction with the stablest frequency, and to build upon them a homogeneous political unit Trade and manufacturing bring people into habitual association whatever their race or creed Ethnic or linguistic divisions which were so much in the consciousness of statesmen after World War I are symbolic in character; they refer to habitual ways of interacting which had, at some time in the past, a technological and environmental basis The growing pains of the modern world system, seen in the present war, are largely the result of the necessities of the existing governments to achieve equilibrium for political institutions built upon the habitual routines of nineteenth century technology Each change resulting from twentieth century technology, brought about compensatory reactions within the political systems, and these in turn brought about greater dislocations in the habitual routines imposed by

environment and technology on the people who were at the same time subject to the rule of these outmoded political institutions Jugoslavia, for example, was united after the last peace on the basis of language, and the struggles between the Croats and the Serbs, which have gone on ever since, reflect the essential geographical and technological disunity of this artificially created kingdom

Where stable technological systems exist, however, people of diverse languages, and belonging to different ethnic groups, have been able to live and work together harmoniously The Island of Great Britain, Switzerland, are but two of many examples where this has occurred. And in all these cases, when the interactions change, the symbols change with them Thus Romansch, Italian, French, and German become Swiss The equilibrium within these countries is not based upon the sharing in common of certain symbols, but upon the stable adjustments of the individuals concerned Stable political institutions can only be based upon the framework of a stable technological system, upon the necessities by which people are brought face to face in their daily life

Once regional states have been delimited, the political system for a United States of the World can be set up The machinery in question must involve a democratic and representative system both for the regional states and for the Federal System with the emphasis within the regions on local autonomy and local initiative The concern of the government of the United States of the World would be upon the administration of those aspects of human relations which involve the interrelations of the regional states Its function, therefore, would be to maintain the world equilibrium by controlling and supervising the systems of communication and transportation, the allocation of raw materials and the conduct of trade and exchange between the several regions

Basic to such a system would be the possession of a world police force, including an army, a navy, and an air force, with no rivals permitted. Of necessity, then the tools of modern warfare—planes, tanks, etc —are reserved to the Federal system, and the regional states would be permitted only militias to keep the peace Unless this provision is incorporated within the organizational framework, a United States of the World cannot operate Every institution, to be effective, has to be able to enforce its decisions, to compel those who will not respond to its authority to learn to do so Within a democratic system, the use of such power is subject to the control of the governed; it can be exercised without bringing about fundamental maladjustments

We cannot give you a detailed blueprint of the workings of such a system It would take time, money and the collaboration of a technical staff to produce such a scheme We can, however, emphasize several principles which are of fundamental importance in its successful operation The first of these is that every regional state, whether it be composed of victors or vanquished, whites, yellows, browns or blacks, must be a member of the world system on an equal basis The administrative hierarchy of the United States of the world would then be made up of individuals from all the regional states, and The Federal Civil Service would operate much like the old Chinese mandarin system, open to all and based upon competitive examinations The exclusion of any group for reasons of expediency or revenge or to maintain a pre-war system of control will only bring about new sources of disequilibrium People learn only by doing, and democratic systems can be made to work only if the individuals concerned are given the responsibility Many peoples who have been excluded from large political systems on grounds of political immaturity, as for example the Hindus, have in fact practiced such governmental methods in their local groups. Once people have been put into a position of inferiority within an organizational framework, it is to the interest of even the well-meaning to keep them there, since, if any change is made, the equilibrium of the superior groups will be disturbed Now, however, the disturbance is so great and so general that the time has come to set such people free

Even Germans and Japanese must be included in our policy, however painful and bitter our feelings towards them Their totalitarian institutional systems, operating under the restrictions imposed upon them drove them automatically on their present course It is of fundamental importance that, this time, they shall not again be provided with the means and the incentive to undergo such violent compensatory reactions, but that on the contrary, positive action shall be taken so that with them as with others a democratic system can operate effectively within a regional framework

The Administration of a World Equilibrium:

As I pointed out at the beginning of this talk, the careful elaboration of an organizational framework within which a world system can operate is an idle effort unless each step by which it is to be put in operation is planned with equal care. In

dealing with human beings, each of whom has specific physiological properties, we must continually keep in mind that they behave in accordance with these properties Once they are conditioned to a particular way of behaving, in terms of which they achieve a state of equilibrium, they tend to remain in that state, and to return to it after minor disturbances For this reason a basic principle of administration is that the means determine the end, once you condition individuals to a particular way of doing things, it is difficult to change the habitual systems of relations in which they interact

Once the war is over and victory has been won, those who are responsible for setting up a new world order which they hope to make stable will be confronted with their most dangerous hour of decision Each step that they take at the time—when the several countries of the world are in upheaval, when the victors and vanquished alike are trying under the stress of old patterns to return to some kind of a balance—will determine whether or not the next step will be possible Temporary measures which are put into operation because no decision has been made as to what permanent steps are needed will themselves become permanent measures, and will shape the organizational structure It is consequently necessary, in setting up a plan for a regional system of federated states, to see what conditions need to be met at the outset

At the end of the war, the victors will be faced immediately with the problem of getting the technological systems back to a working peace-time basis This means that not merely will it be the responsibility of the victors to disband the armies and to feed the starving populations, but to see to it that manufacturing and trade shall return to some kind of stability We are all of us conscious of the problem involved in our own country, and it has been the concern of private agencies and of the Federal government to set up plans by which full employment can be maintained and the productive operation of our industrial system transformed into peacetime products But this problem must be faced in every region of the globe, and the successful implementation of a technology capable of attaining equilibrium cannot be worked out after the armistice is signed, it must be prepared beforehand

If such planning is done in detail before the war is over, it will then be possible to utilize the necessities of feeding the populations of the world, and of repairing their economic systems, as ways of conditioning the individuals in these populations to the new political system. If the framework is drawn up in advance and ready to put into operation, those who wish to introduce this system can use the administrative necessities of the post-war period for this purpose Representative systems can be set up in the several regions to aid the administrators in feeding the populations, and in working out and directing the technological changes needed to provide reemployment for the armies In this way there need be no period of temporizing in which the old habits and systems can reassert themselves, compensatory reactions can be directed within new channels and not left to find their way back into the old

Such plans cannot be directed and administered unless continuous control is maintained over the developing systems of human relations Systems of human relations, like all other systems, vary within fixed limits when they reach equilibrium It must be part of the routine activities of the administration to take periodic samples within the different regions, in order to determine whether or not changes are occurring outside the limits of tolerance of the system in question and to take the necessary administrative action By the use of such control methods, it will be possible to estimate the effect of a new technique upon the equilibrium, and to see to it that each increase in technological efficiency is fitted to the existing organization so that it produces an increase in the adjustment of human beings

Such a democratic system, however, capable of attaining a state of equilibrium on a worldwide scale, can never operate unless we plan what we are going to do, long before we are called upon to do it The conversion of a single nation to readiness for war requires years of careful planning before an M-day is feasible The far more complex organizational framework for a United States of the World cannot be left to the chance inspiration of the day after peace has been won We must have in our hands a careful outline of the precise steps to be taken and the order in which they are to be timed, as well as an organizational blueprint for the system as it is intended to operate.

If we are to succeed, time is of the essence The longer we wait after the final victory, the more time is given for the various countries to return to a status quo ante bellum, and the harder it will become to introduce new systems of relations to which people must become conditioned Our plans for V-day must be fully worked out, ready to put into operation if and when the event occurs. Lack of preparation for peace can be even more fatal than lack of preparation for war, for unless we prepare for peace, we can never hope to see an end to war.

VII

INTERNATIONAL UTOPIAS

By Zechariah Chafee Jr

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"Let us conceive of the whole group of civilized nations as being, for intellectual and spiritual purposes, one great confederation, bound to a joint action and working toward a common result, a confederation whose members have a due knowledge both of the past, out of which they all proceed, and of one another This was the ideal of Goethe, and it is an ideal which will impose itself upon the thoughts of our modern societies more and more"

In this intellectual and spiritual confederation envisaged by Matthew Arnold, we scholars brought to maturity whatever within us is good for others. The Tercentenary of 1936 honored it as well as Harvard That was its last blossoming Already the Nazis in Germany and Franco in Spain had begun the long sequence of tragedies which, for the second time in our lives, has torn asunder the Western world of art and science and ideas For politicians and soldiers let it be a war between groups of nations For us it is a civil war within the single community of thought

Arnold might assume in 1879 that this intellectual and spiritual confederation could continue in a Europe which was for other purposes divided into irregular compartments, that its unity would not be severed by the barriers of tariff walls and frontier fortresses The two civil wars, thirty-five and sixty years later, have shown us the falsity of his assumption National boundaries can impede the free flow of thought more than they do the less sensitive currents of trade The confederation of the spirit envisaged at Weimar is superseded by the New Order conceived in Berchtesgaden

And yet the ideal of Goethe and Arnold is one of the chief reasons for my belief that the International Utopias of which I shall speak are more than the baseless fabric of a vision Europe was one in the ways that they accounted most important. That makes it easier for it to become one again in a greater number of ways This confederation of the mind and spirit was real and had been real for centuries There is something there capable of taking on new functions and influencing still more human activities

A second reason for confidence is economic I need not indulge in commonplaces about the annihilation of space, but merely illustrate what I mean from the war itself The mobility of the very tools of destruction—airplanes, troop-trains, and tanks passing rapidly from Narvik to Crete—shows the growing meaninglessness of the old national boundaries So does the coordination of factories creating those tools of destruction However vile the present purposes, Europe is unified industrially as never before May it not be possible to change the purposes and yet preserve the unity?

As a third witness let me summon Hitler himself His New Order is a negation of nationalism and racial isolation It is federation—of a very bad kind, surely, but yet it is federation, which Europe never had before Countries formerly separated are now associated as master and slaves—they may later be associated as comrades in a common enterprise A conqueror sometimes benefits his foes more than himself Napoleon erased the outworn boundaries of many petty German states, but the resulting unified Germany passed to the very dynasty he fought So Hitler may be wiping out wider boundaries so that soon the agents of a democracy may govern as uninterruptedly as his minions do now

The instability which succeeded the Fall of the Roman Empire has persisted until the present day Rival nations sliding about over each other have produced periodic earthquakes like sliding strata of rock This war, in its early stages at least, is only the latest of a series of often senseless struggles, wars of this or that succession, whose repercussions used to loose the Indians on our forefathers and now have turned the Japanese upon us To an American vexed by these constant quarrels, they seem likely to continue so long as an area smaller than our own is split among over a dozen independent political units each pulling in a different direction against the others and against the growing strength of the uniform techniques of industry which ignore national boundaries. In a sense, Europe has always struggled to reinstate the *pax Romana*, and now may be the best chance it has ever had to do so, albeit in a nobler form than either Trajan or Hitler conceived

In short, with all our misfortunes, a central government for Europe—or even for the world—becomes more practicable than it was in 1919. We do not know yet what spirit will imbue that gov-

ernment Oddly enough, its spirit seems likely to emanate from Germany whichever way you look at it On the other hand, the New Order of Hitler, on the other, the European confederation dreamed of by Goethe and Immanuel Kant Or shall there be a third course—all the old independent states once more?

May I venture an analogy from a remote part of the world? During the centuries when Greece was falling apart and Rome was expanding, China was divided like modern Europe into many warring states They fought with traditional etiquette, changed boundaries kaleidoscopically, yet still remained numerous and bellicose Meanwhile, the teachings of Buddha and Confucius spread regardless of boundaries Meanwhile, the irrigation systems so necessary for Chinese intensive agriculture went on expanding The interdependence of these canals called for a unified control of all the water in China Nevertheless, political divisions threatened to wreck what should culturally and economically have been a single community About the time of the first war between the Romans and the Carthaginians, a people called the Ch'in started conquering the rest of China They did not fight like gentlemen, as other Chinese did They beheaded their defeated foes In 221 B.C, just before Hannibal crossed the Alps, they overcame their last antagonists, the Ch'u At last there was one control of the water system Bad as the Ch'in were, they had done the job And just because they were bad, they were replaced in fifteen years by the Han dynasty, the first great rulers of a unified China Ever since Chinese historians have hated the Ch'in [2] It may be possible that the Nazis have with even greater cruelty accomplished the task of unifying Europe so that more enlightened successors may soon do good that was never possible before

Along with these three factors working for unification, we have an entirely different reason which impels men powerfully to try to bring about some sort of unification I refer, of course, to the inescapable evidence that the alternative is recurring warfare. We know well that science has made war vastly more costly and more destructive, and will accelerate this tendency, that it is increasingly unlikely for a war to be localized between two countries—once started, it spreads rapidly over the world We know that the intervals between wars can be very short unless we do something to make peace effective. It is just as well, perhaps, that the Second World War came so soon after the First, so that we cannot ignore this lesson. We know that hereafter, unless a better order be established, even an interval of peace will be almost as bad as war, for hereafter nobody will dare to refrain from preparing, preparing, preparing, at enormous cost You can have strong defense, or you can have civilization, but you cannot have both Even peace will be a total organization for war, crushing out education, recreation, books, family life. This road leads straight to mass suicide—a feverish peace followed by what Kant described as "A war of extermination, where the process of annihilation would strike both parties at once would bring about perpetual peace in the great graveyard of the human race"

So there is, more than ever before, eagerness to establish something new which will prevent this ruin of our race And the opportunity will come after victory What shall we do with it? What sort of new world is desired? Several sorts, in fact Many books and magazine articles have already broached different schemes, although the subject of post-war organization has not yet received much attention in daily newspapers There is some danger that people will get so bewildered by all the overlapping and conflicting proposals that they will throw up their hands in despair and stop thinking about the whole matter That would be a great misfortune, for an enlightened public opinion on the right use of the victory for which we strive will do much to save us from throwing that victory away

On the other hand, some persons incline to seize on a single scheme and fervently hail it as a cure-all with no thought of adverse criticisms and alternative possibilities Fanatical devotion to one plan at all costs wearies listeners and alienates supporters of other plans Competing zealots may raise such a clamor that they will silence each other and disgust everybody else So no features of any international scheme will win general acceptance, and we shall be back to some form of the balance of power

Consequently, it is wise for Americans to consider more than one scheme, yet not too many schemes There are four main types of International Utopias that have considerable influence Each of them stands out pretty distinctly despite many divergences among its supporters about details Consequently, it will simplify the problems of post-war organizations to distinguish these four schemes from one another, and illustrate each of the four by means of a brief description of a significant book.

At the outset, I want to make it plain that all four plans are like the famous recipe for hare soup,

which began "First catch your hare" Every International Utopia presupposes the downfall of Hitler and the other Axis rulers

I

The first plan is to improve and strengthen the League of Nations In twenty years it showed several kinds of defects Its most outstanding failure was the breakdown of economic sanctions against Italy during the invasion of Ethiopia in 1935 Hence there has arisen a strong movement in favor of stronger sanctions and more effective methods for bringing sanctions into operation It is to be made really a League to Enforce Peace An able and very thorough presentation of methods for this purpose is made by an Englishman, Lord Davies, in a book of seven hundred pages entitled "The Problem of the Twentieth Century" Lord Davies is an elderly man He became the active head of The New Commonwealth, an international society devoted to the establishment of an international police and other devices for strengthening the League It published a number of research monographs His book suffers from being older than the other books I shall discuss The first edition was published in 1930 and a revised edition in 1934 Hence it is not in form a post-war plan but its reasoning is capable of adaptation to the situation which confronts us

After a full and informative analysis of older proposals for international unification, like those of the Abbé Saint-Pierre and Kant, he takes up more recent expressions of the idea of an international police force I was surprised to learn that in 1910 both Houses of Congress passed a resolution asking President Taft to appoint a commission of five to consider among other aspects of disarmament "the expediency of constituting the combined navies of the world an international police force for the preservation of universal peace"[3] Taft took some steps but no cooperation then seemed feasible Although Wilson at Paris dropped force out of the League, this was inconsistent with his utterances of January 22, 1917, in his speech on Peace without Victory

> "Mere agreements will not make peace secure It will be absolutely necessary that a force be created as a guarantor of the permanency of the settlement so much greater than the force of any nation now engaged or any alliance hitherto formed or projected that no nation, no probable combination of nations could face or withstand it If the peace presently to be made is to endure, it must be a peace made secure by the organized major force of mankind"

Lord Davies would carry out this proposal of Wilson and expand the idea in the congressional resolution so as to include an army and an air force as well as a navy

Under his plan there would be three types of police (1) the ordinary police we have now to maintain local order, (2) a national body of police in each country to maintain national order and supplement the local police, (3) an international police force to maintain international order Their two principal functions would be to repel aggression and to enforce the decisions of the World Court and arbitration tribunals Unlike the Holy Alliance, the League is not to intervene in the domestic affairs of either members or non-members A fortiori another state is to be kept from so interfering

One of Davies's most interesting points is that the progress of invention has now made possible a differentiation of weapons, so that the international police can be armed much more powerfully than will be allowed for any national body Some sort of differentiation has long been common inside a country The local police carry clubs or at most revolvers, while the national guard and the army carry rifles According to the plan of Lord Davies, each national army would be limited to weapons existing before 1914, whereas the monopoly of the newer and more powerful weapons would be possessed by the international police These would include submarines, airplanes, poison gas, tanks, the new heavy artillery and bombs All these weapons would be forbidden to the national armies Such a differentiation was proposed by France at a disarmament conference in 1932 The Washington conference of 1921 also furnishes a precedent, for differentiation was there used in a negative fashion to forbid certain powerful weapons and reduce others while some weapons were left unrestricted If the proposal of Lord Davies could be effectively carried out, it would have two great merits In the first place, it might very well make the international force more powerful than any combination of member states with their limited equipment A combination of outside states would be met by an even stronger force as I shall show later On the other hand, his plan would not impair the ability of each state to maintain law and order in its own territory The burden of the international force would be met by contributions from member states in personnel, arms, and money States which failed to contribute would be unable to participate in the management of the League, whereas in the past no such

penalty was imposed and Peru even obtained a seat on the council after it had been years behind on its annual assessment A delinquent state would also be denied the use of the international force for the protection of its own frontiers Another new device would be an international general staff which would render the international police effective and mobile. Thus sanctions would be organized before the crime was committed, whereas the actual League has been greatly handicapped because the economic sanctions which it could use had to be worked out after the violation of law For instance it was several months after Italy invaded Ethiopia before the League could decide what to do The international force would embrace all the instruments of coercion If it consisted of a navy alone, as Congress proposed in 1910, it could not have prevented the German army from overrunning Europe in 1914 Hence an army and air force must be included Perhaps the development of aviation will eventually make an international air force sufficient

How shall the international police force be organized? Davies describes three alternative schemes

(1) It will consist entirely of quotas furnished by the member states, each of which will control its own quota and pay its cost in time of peace However, a general staff at international headquarters will organize these scattered quotas, and on mobilization it will take them over under international command This was the French scheme at the Versailles Peace Conference One advantage is that it would cause a minimum amount of interference with existing national establishments and yet bring about considerable disarmament in each country However, there are several disadvantages There is no adequate guarantee that a nation would meet its obligations when the crisis arose, and thus the League might lack the support it had counted on This uncertainty would discourage apprehensive nations from diminishing their national forces Also, it would fail to eliminate competition between the war offices and admiralties of different countries A national staff would resent the intrusion of the international staff. When each nation retained financial control during peace it would be tempted to spend more in making more, to prepare peace industries for transformation into munition factories, and to invent new weapons for its own use Secession is made easy, just as the southern state militias in 1861 became the Confederate Army Finally, this scheme disregards the hopeful new opportunity for differentiation of weapons.

(2) At the other extreme is a complete self-contained international force, with the abolition of all national forces except as they are necessary to maintain internal order This scheme would have the advantages of eliminating all competition between countries, obtaining comprehensive disarmament at once, producing increased mobility of the international force and simplifying the problem of organization On the other hand, the disadvantages are numerous The League would have to possess a bigger force than it would ever be likely to use This force would be much more expensive to maintain than national quotas Even if some of it could be kept within international territory, considerable portions would have to be garrisoned inside member states, which would cause disputes The problem of maintaining internal order would become much more difficult Each country would be stripped to its local police who would have no national army to fall back on. Finally, since there would be no liaison between national and international staffs, the people of each state would be wholly cut off from the international force and might cease to regard it as a genuine part of their own defense system

(3) Therefore, Lord Davies favors a compromise scheme He would have a composite force both national quotas and a specialized contingent which should be enlisted, equipped, and controlled by the League This plan was proposed by General Gerard, a far-seeing Frenchman, in 1923 Here Lord Davies's ideas of differentiation of weapons would have full scope The separate national quotas would be armed with older weapons, and the international contingent with newer weapons He finds many advantages in this scheme First, the central contingent would have unmistakable superiority over the armies of member states, which would be decisive in an emergency It could also hold off outsiders long enough to give time to assemble the national quotas, and the combined force would then be overwhelming. Second, competition in the invention and manufacture of new weapons would be abolished Third, substantial disarmament would be produced unless a non-member state starts competing Fourth, it would give permanence to the League, for a member would be unlikely to withdraw once it had surrendered its most potent weapons. Fifth, the sovereignty of states is preserved for they would control their quotas, and the central contingent is dependent on their contributions Sixth, the

scheme is practicable. The technical arrangements of each country go on, of the older sort. The international police is small with specialists as aviators, tankmen, etc Its small size simplifies the problem of international barracks and bases It also renders the central force very mobile Seventh, the continuance of a liaison between the national staffs and the international staff makes every nation directly interested in the efficiency of the central contingent and in fruitful cooperation with the League military authorities Eighth, self-defense is recognized in a relative form. The frontiers will be guarded by their own national quota, then by the rapid arrival of the central contingent, and finally by the later mustering of the quotas of other members of the League Thus the third scheme meets the objections to the first two

The international force will owe allegiance to the League like the present Secretariat and will presumably cease to be citizens of their former states The headquarters and bases will be independent territory of the League, like the District of Columbia and the federal forts in our country During a twenty-five year experimental period, which Lord Davies shrewdly advises, these territories might be merely taken on lease The bases should be chosen for their strategical position, access to the sea, and suitability for fleets of airplanes They should not be too close to any great powers He proposes Palestine as the District of Columbia, because it satisfies these requirements and has strong associations for citizens of so many countries Other strategical points to be occupied include Suez, Panama, Singapore, Djibouti, Corsica, the Hawaiian Islands, Constantinople, the Aaland Islands, and Yap It might also occupy neutralized zones like the Rhine Valley, the Dardanelles and Bosphorus, and the Great Lakes Small states might lease part of their territories as part of their contribution, receiving full protection in return For example, Albania, Monaco, Latvia, Honduras, Newfoundland, and Haiti The League would have its own aircraft factories, and it would ration orders for other munitions among many states, storing them at international bases

Although this sounds very elaborate and some details would certainly be rejected by the United States, it seems possible that the international police would become less costly as the world became increasingly habituated to peace Lord Davies wisely observes that a good centralized police force tends to eliminate all force, including itself

In order that the international police force may be satisfactorily organized and operated Lord Davies would remove a second usual objection to the Covenant, namely, the requirement of unanimity for most acts of the Council He would have an executive body capable of managing the police and of enforcing sanctions and the decisions of international tribunals The prompt action of the executive must be assured by the residence of representatives of the member-states at the capital The actual executive must not be too large or unwieldy Countries should be excluded which do not maintain international order or fulfill their obligations, including the payment of contributions The apportionment of contributions would be based on wealth and other factors as well as population This does give big states an advantage, but they already possess this now for the purpose of piling up armaments They will be equal in the judicial sphere, the privilege of representation on the assembly and freedom to criticize Small states as a class will be represented on the executive body Instead of the rule of unanimity he would substitute a two-thirds vote, thinking a majority too much liable to make mistakes

Several objections to the plan of an international police are discussed by Lord Davies himself and also in a shorter book on "Theory and Practice of International Police," by Professor Hans Wehberg, a German scholar long teaching in Geneva (1934) Here are some of them

The force may suffer from disloyalty within, because policemen will be more devoted to their countries of origin than to the League In reply writers point to the success of the French Foreign Legion, the Swiss Army, the composite army of the Allies in the World War, and the frequency with which men change their allegiance on migration.

Secondly it is urged that a single nation or group of nations could overcome the police either by a sudden attack or by secretly acquiring a considerable supply of the strong weapons Lord Davies deals pretty well with the danger of sudden attacks, in view of the mobility and strategic locations of the international contingent. The quota of the attacked nation would be able to hold up the invasion for a while, so long as the invaders possess the same sort of weapons However, this reply is greatly weakened if the invaders have secretly acquired airplanes and tanks Lord Davies does not sufficiently show how the monopoly of these strong weapons in the central contingent is to be maintained, or how a member country is

to be prevented from inventing and using new devices This seems a particularly serious danger.

Third, one power might try to get control of the central contingent Fourth, this might go in for politics on its own and behave like Wallenstein's army in the Thirty-Years War or the Roman army in bad periods of the Empire, ready to go anywhere under a leader who promised high pay and abundant loot The reply of Lord Davies to these two objections is that treachery and conspiracy would be difficult in a force with three divisions for land, sea, and air, each having a separate head for a limited period of time, and all paid by the executive He doubts if one state or one leader could influence all the heads and all the divisions Although I am not entirely satisfied by this reply, Lord Davies goes on to give a better reason "Every scheme has its risks Every federation has been faced with the possibility of the disruption of its central force Every government is liable to be deprived suddenly of its sanctions These possibilities are inherent in any political system, national or international, but it does not follow that they will be realized The effective safeguards are to be found in the public opinion of the countries participating in the confederation, and in the common sense of the international police"

Over and above this, the international police must not be viewed in isolation The success of this device depends much on the general strength of the League as a guardian not merely of formal international law but even more of the idea of justice in a broad sense The peoples must want to cooperate in the League, not in order to keep down a certain group of states, but in order to serve the well-being of the world In other words, security and disarmament and just international relations are three interdependent factors Lack of any of the three interferes with the two others It is proper to isolate each of these factors for purposes of study and detailed discussion, but in the end they must be considered together and all treated satisfactorily

Therefore, it is important to cure not only the two defects in the Covenant already mentioned—weakness of sanctions and the unanimity rule, but also to remove other defects which have produced a strong sense of injustice Three of these may be mentioned First, the handling of minorities is poor, and produces a feeling of insecurity in the majority and of injustice on the other side of the boundary line. One suggestion is periodical visits by a League inspector, who would ascertain the facts, deflate peevish complaints, cut through the excuses of the majority, and often be able to effect compromises before quarrels become serious Also a Minority Commission at the capital would receive periodic reports from governments with minorities and be able to question their officials Next, although the mandate system is an advance on previous practice, several writers advocate that all non-self-governing territories should be administered directly by the League, which should undertake to fit them for independence and conserve their raw materials for the benefit of the natives as well as that of consumers generally and not to profit investors or governments Finally, there must be an effective machinery for the peaceful change of treaties and boundaries which have been rendered unsuitable by new conditions The powers of the League under Article XIX have been narrowly interpreted and never used Some writers would transfer the power to make just changes from the Council to the World Court, but any lawyer will realize the danger of trying to combine the judicial settlement of disputes which are suitable for the application of general rules of law with the uncontrolled exercise of a vague sense of fairness It would be much as if our Supreme Court added to its present functions the power to determine how big an income tax the rich should pay in order to provide funds for the WPA

Even if defects in the covenant are remedied by the establishment of an international police and other devices like those described, the League is not likely to succeed unless there be also a new spirit Of this I shall have something to say later

II

Instead of a League, it has been widely proposed that nations should form themselves into a Union The difference between these two types of international organization is very important In a League the nation is the unit Each national government selects its representatives for the central legislature and executive groups The central government is financed by contributions from the treasuries of the member nations In case of any violation of international agreements, coercion is exerted on the government of the nation which is committing the violation. A Union, on the other hand, makes every human being within it the unit The citizens of the member-nations elect their representatives to the central legislature and perhaps also vote for a chief executive official The central body imposes taxes directly on citizens The force of the central body is exerted against the individuals who are responsible for international wrongs The cen-

tral government takes charge of matters of common importance like defense against aggression, while the national governments confine themselves to the affairs of their own respective territories The difference between a League and a Union is, in a general way, like the difference between the Confederation of our thirteen states which fought the Revolution and the national government which was set up by our Constitution in 1789

The leading advocate of a Union is Clarence K Streit His "Union Now," a book of three hundred pages, has gone through many editions, and societies with local offices in numerous cities to support his plan are active both in this country and in England The book first appeared in October, 1938, shortly after the Munich crisis Mr Streit then proposed that fifteen North Atlantic democracies should immediately form a Union, which would be capable of growing into universal world government as other nations qualified themselves for admission by establishing popular self-government and civil liberties His fifteen democracies were the United States, the United Kingdom and five Dominions, Switzerland, Sweden, France, Belgium, the Netherlands, Denmark, Norway, and Finland Unfortunately, six nations at the end of this list have since become ineligible So, outside the United States and the British Empire, nothing is left of his nucleus of a world government except Switzerland and Sweden

Under the Streit plan, the Union government would deal with five matters of common importance—citizenship, the maintenance and use of defense forces, customs with international free trade, money, and the postal and communications system Other powers would be reserved to the national governments, and the Union would guarantee to each nation protection against enemies, foreign and domestic, and the maintenance of democratic self-government and those rights of man that exist in all the democracies.

In Streit's illustrative constitution the Union will have a Congress of two houses, elected by popular vote The lower house will be roughly apportioned among the member-states according to population, while each state will have two senators except that four would come from France, Great Britain, and the United States An Executive Board of five men will be chosen, three by popular vote, one by each house of Congress The judicial power is vested in a High Court.

Streit argues at length that such a Union is superior to conceivable alternatives The old balance of power can no longer keep peace, and neither can limited alliances "We get peace by putting so much weight surely on the side of law that the strongest possible lawbreaker cannot possibly offset it and is bound to be overwhelmed" He stresses the weakness of any League of Nations It cannot act in time, because as he thinks, a League cannot escape the unanimity rule To get the agreement required for action not only all the delegates must be persuaded, but also the governments behind them, and in democracies this means that the legislatures must be persuaded too By contrast, a Union can act swiftly through a majority vote of those on the spot Consider the speed with which New Deal measures were adopted in the United States Furthermore, a League cannot enforce law because it must operate against a state No big state can be coerced You cannot indict a whole nation Even if the League succeeds, the condemned people is resentful What makes matters worse, the nation which is the lawbreaker in one incident still sits as judge over a different lawbreaker Thus Italy while undergoing sanctions still took part in League hearings on Germany's violations of the Locarno Treaty There is no sheriff in a community where every man is equally sheriff Streit raises similar objections to a permanent League police force

Objections about the difficulties of inaugurating the Union are met by the persuasive analogy of our own situation in 1787 The makers of our Union went straight ahead, unafraid of the future

> **"Yet they lived in a time when New York was protecting its fuel interests by a tariff on Connecticut wood and its farmers by duties on New Jersey butter, when Massachusetts closed while Connecticut opened its ports to British shipping, when Boston was boycotting Rhode Island grain and Philadelphia was refusing to accept New Jersey money, when the money of Connecticut, Delaware and Virginia was sound, that of all other States was variously depreciated and that of Rhode Island and Georgia was so worthless that their governments sought to coerce the citizens into accepting it In those days New York was massing troops on its Vermont frontier while the army of Pennsylvania was committing the atrocities of the 'Wyoming massacre' against settlers from Connecticut"**

Variations of this plan for a Union have been set forth by other writers Thus Grenville Clark, a leading New York lawyer and a Fellow of Harvard, published at the end of 1939 "A Memorandum With Regard to a New Effort to Organize Peace and Containing a Proposal for a Federation of Free Peoples" His scheme differs from Streit's in limiting the powers of the Union at

the start to defense only. Also he would add to Streit's fifteen members Argentina, Colombia, and Chile The most influential English book appears to be W B Curry's "The Case for Federal Union," which adheres closely to Streit's plan. This pamphlet of over two hundred pages was published in the autumn of 1939 after the outbreak of war

Many of these proposals for international political organization remind me of some plans for an international language An American urges that life would be much simpler if everybody spoke English, while Mussolini predicts a Europe where Latin will once more be universally used The originator ends where he starts, in his own country In the same way the draft constitutions of Streit and Clark, both Americans, bear a close resemblance to the Constitution of the United States On the other hand, an Englishman, John S Hoyland, has produced an interesting little book of one hundred pages, "The World in Union," which though falling within Streit's general scheme makes considerable use of English experience with administrative bodies of experts For instance, he proposes a world economic council, composed of representatives of employers, employees, and citizens generally, which would be in charge of reconstruction of areas devastated by war, and readjustments due to the introduction of free trade from which some regions now having a high tariff would suffer for a time This council would also bring oriental countries up to the same standard of living as western countries in order to prevent the latter from being flooded with cheap labor, and would seek to eliminate poverty all over the Union

Hoyland has given us a better book than Streit's, which I find very heavy going Some of the divergences are due to Hoyland's strong religious feeling, which is especially prominent in the last chapters. Unlike Streit, he wants no sanctions "The peoples must want to come into the Union " Also Hoyland would include the Axis Powers and Russia despite the undemocratic nature of their institutions To the objection that Union is then risky he replies that it is risky anyway and even more so if sanctions are inserted and several great powers are excluded from membership "You have to trust the future Take one step at a time Do the right thing now, and believe that as you do the results will be sound and attractive enough to quell the spirit of violence and separation before it comes to strength " On the other hand, he says "There is no future for national sovereignty " It will shatter civilization

The diminution of democracies since Streit published "Union Now" after Munich has led him to write a second book "Union Now With Britain" (1941), proposing that the United States should at once federate with the British Empire.

Some kind of association of the English-speaking countries seems more probable than World Union or the other three schemes I am discussing[4] China and Russia, for which Mr Streit did not allow, are likely to be partners too However desirable such cooperation of the victors, it is not an International Utopia An association to enforce the terms of peace upon the vanquished and nurse the occupied countries back to order and prosperity may prove necessary and do its work very well, but it is only a temporary receivership although it may last for years No four governments, however enlightened, are wise enough to run the rest of the world altruistically for decades Sooner or later the conquered and occupied peoples will demand the return of self-government and a share in the process of world-administration If this demand be denied indefinitely, trouble is bound to arise Our Congress will get weary of paying a quarter of the cost of policing the world The excluded nations will try to band together against the Big Four inside, and the so-called Union will be little more than one alliance against another Finally, not all the internationally-minded statesmen live in the United States, the British Empire, China, and Russia Whatever the shortcomings of the League, it revealed such statesmen in France, Germany, Scandinavia, Latin America, and elsewhere The task of international organization will be very difficult, and it would be fatal to reject the help of the best men wherever they live

Therefore, an association of victors should be regarded as only a transition to something wider, and the problem still remains—what shall this something else do? Even if the four principal Allied Nations now form a Union like Mr Streit's, this cannot be forced down the throats of other countries when they do revive When general participation becomes practicable, it will not succeed unless the scheme is reasonably satisfactory to the new members as well as the old Everything must then be reconsidered The result may be an expansion of the arrangement among the victors, whether Union or something looser, it may be a strengthened League of Nations; it may be one of the two schemes still to be described

III

The difficulties of world federation have led some writers to substitute a more modest scheme

for federation in Europe alone. An interesting book of this type is "The United States of Europe," by Alfred Bingham, who is an American and edits the magazine "Common Sense" His book was published in 1940 before the fall of France

Bingham favors a Union resembling Streit's, but with smaller powers over a smaller area He believes it best to use what we have whenever possible, rather than attempt to build a completely new and more logically perfect structure He would omit the United States because we are less prepared to surrender our national sovereignty than are European countries, the Soviet Union, because it covers two continents and has different institutions, and the Far East, because it has its own problems "Federations have grown up where there were some fairly obvious common interests and the possibility of a common loyalty." Europe meets these tests The idea of European unity, though subconscious, has always existed in the European heritage There is the common background of Greek thought, Roman Law, Christianity, the use of Latin, even the same habits and clothes Unity was approximated by the French Revolution and Napoleon The idea has lately been popularized by Count Coudenhove-Kalergi, Rathenau, and Briand, who was partly moved by the desire to confront American prosperity with a strong Europe. Plans for a customs union have been brought forward European workmen have been joined together by a single song, the Internationale Bingham stresses the long establishment of numerous international bodies for mail, telegraphs, health, the navigation of the Danube, copyright, electric power, agriculture, banking, and the regulation of maritime affairs like lighthouses and buoys These bodies have been called bricks without mortar They need something vital to draw them together Also Europe has had a considerable experience in the theory and practice of federalism in Switzerland, Germany, and the British Commonwealth, besides Russia which he would exclude

Bingham's Union is looser than Streit's He would not speak of secession one way or the other. He would not require the internal government of member states to be uniformly democratic India shows the possibility of diverse institutions within a federation Instead, he would meet persecution by allowing the victims to emigrate freely and take their property with them. Then he would wait for the dictatorships to alter, believing that the federal structure of Europe as a whole will encourage local democracies Unlike most post-war plans, this book does not emphasize disarmament. Bingham believes that armaments are a superficial symptom of deeper disorders Peace within the United States of America, he says, is not due either to the national army or to abolition of state militias. He would like to forget the term "international police force" Coercion of a state or its inhabitants is war The only genuine protection against civil war inside the federation is good government Although he would meet external aggression with an international army which should have the monopoly of offensive weapons, somewhat in accordance with the plan of Lord Davies, Bingham believes that the real answer to competitive armaments is the maintenance of high standards of government which will rapidly demonstrate the advantages of European union War will be abolished when government has replaced anarchy in areas now left to the arbitrament of force

As to boundaries, Bingham says that ideally Europe, at least west of the Vistula, should be a single economic area with complete freedom of movement for men and materials, having merely those administrative subdivisions that prove convenient It is not practicable to go that far now However, one practicable and valid principle for political boundaries is to make them mean as little as possible This is better than attempting to redraw political boundaries "New boundaries raise as many problems as they settle The less tinkering with boundaries the better" One way to makes boundaries mean less is to have different boundaries for different purposes as in our country, where the federal reserve districts are not coextensive with a state or with other kinds of federal regions In the same way European political boundaries need not coincide with cultural boundaries for the language used in schools, etc , or with economic boundaries set up for labor regulations, river traffic, or the efficient industrial administration of a coal and iron area The desire for cultural autonomy, which has been so troublesome in the past, can be better satisfied in a federation than with independent nations on a military basis For example, Alsace might then develop in its own way without being suppressed by either France or Germany

The central government would maintain the army (for defense and not as a police force) and a navy. It would carry on foreign relations though national diplomacy would continue. It would have power to tax individuals, protect minorities, and hold a plebiscite in any region on the question whether it should become partly or wholly autonomous.

Sub-federations would be possible, for instance in Scandinavia or the Balkans This would be like the New England Conference of Governors Indeed, European federation may, Bingham thinks, be preceded by several attempts at partial federation, already illustrated by the close association of England and France during the first months of the war

Colonies outside Europe seriously complicate any plans for European federation It is too simple to throw them all into a single melting pot You could not include the Dominions, India, or Algeria However, colonies are less important than the "have not" countries think Instead of pooling or redistributing non-self-governing colonies, Bingham would give the Union considerable power over colonial administration The greatest need is that the resources of a colony should benefit its inhabitants He compares a colony to the zinc and lead region in the Ozarks, which enriches outside investors and leaves the natives poor and unhealthy International agencies should be set up to regulate investments and the conservation of scarce resources, and this should be done for the benefit of the inhabitants, consumers all over the world, workers, investors, governments, and future generations The mandate principle is sound when really applied, but he thinks the European Union would carry out this principle better than the League

The United States of Europe would exist within the League of Nations There might also be other international organizations like the Pan-American Union, the British Commonwealth, the Soviet Union, an association of Far Eastern nations, and perhaps one of the desert peoples of North Africa and the Near East These regional unions in Europe and elsewhere may prove only a brief interlude before world federation

In conclusion, Bingham warns us that perfection is not just around the corner any more than prosperity. Our own Constitution succeeded only through compromises, political deals, and the accidents of personality

A somewhat different plan for European Federation is proposed by Arnold Brecht, a professor at the New School for Social Research, in a stimulating article in the Harvard Law Review for February, 1942.[5] Mr Brecht, being a German, escapes from the usual analogy of our Constitution. Instead, he derives several interesting suggestions from the German Confederation of 1815–1866, which, as he observes, worked better than the League of Nations. "It soon resulted in sweeping eliminations of tariff barriers and it succeeded in preserving peace for about fifty years Its end was not anarchy, but a more perfect union, plus an alliance." This article suggests the reflection that we need a cooperative endeavor to frame a plan for international organization In a group of experienced men from different nations, each would be able to contribute fruitful ideas from his own governmental system The resulting combination would be more likely to win acceptance from many countries than would a plan shaped largely by the political institutions of the United States or any other single nation.

IV

The last book to be considered at length is very hostile to the views of the other three books. It is "Federal Illusion?" by D M. Pritt, a prominent English barrister and a Labor member of Parliament This was published in 1940, apparently before the fall of France It advocates a Socialist Union like that in Russia

The chief position taken here is that war cannot be ended by proposals which leave our main economic structure untouched The causes of war are economic, as socialists said long ago, and only socialism will insure peace War is due to the effort to get into closed markets and obtain new fields for investment and new sources for raw materials However, war is impossible between socialist states They cannot quarrel over exports There are no private interests, and the socialist system of producing what the people need and enabling them to buy it eliminates the whole element of scarcity of markets Your country is your own market You produce all you can consume, and consume all you produce Nobody fights over water when there is no drought International trade in a commodity then becomes just a question of convenience, it does not make the rich profit or the poor starve There is no quarrel over the exploitation of colonial races, when there are no colonies, no exploitations, no private capital

Because war is inherent in the nature of modern industrial states and the men who hold power in these, all previous schemes for peace have failed Arbitration, formerly regarded as a panacea, does not affect the deeply-rooted conflicts of interest between rival states. The League of Nations failed because it was always designed to be an instrument for securing the protection of the imperialist and economic system of the major powers If these interests prevented the League from fulfilling its limited functions, they would a fortiori prevent

any wider federal union from operating under the present economic system So Pritt's argument runs.

The requisites of a successful federation are then analyzed with considerable shrewdness Not every group of states will be willing or able to federate effectively or even ineffectively Dicey laid down two conditions for federation (1) A body of countries like the Swiss cantons, the American colonies or the Canadian provinces so closely connected by locality, history, race, or the like, as to be capable of bearing an impress of common nationality in the eyes of their inhabitants (2) The existence of a very peculiar state of sentiment among the inhabitants of the member countries—a desire for union and not for unity There is no basis for federalism if there is no desire to unite For example, the scheme in Cromwell's time for uniting England and the Netherlands was one of those dreams which may haunt the imagination of politicians but can never be transformed into facts On the other hand, a desire for unity will lead to a single nation rather than federalism Dicey adds that the distribution of the different powers of government between the central body and the member states, which federalism necessitates, requires courts to possess authority to act as interpreters of the Constitution Federalism substitutes litigation for legislation Hence it can flourish only among communities imbued with the legal spirit and a reverence for law Furthermore, each federation has grown up under historical conditions peculiar to itself and its own reasons for existence The United States grew out of common aims in a revolutionary war and a rising capitalist economy which demanded for its proper functioning a national market There was no probability that competitors would amicably federate with it Even the extension of American sway over our present area was not idyllic, for the Indians were exterminated, new territories were acquired by war with Mexico, and a great Civil War occurred

The federal union advocated by Streit and others fails in Pritt's opinion to satisfy the requirements laid down by Dicey The great powers have no real desire to surrender any part of their sovereignty in the political, financial or industrial field They want to hold on to every fragment of power they possess Even if disputes were settled by the executive or the legislature, it would be hard to get acceptance There is even less chance that the decisions of courts would be accepted, and such acceptance is essential in federalism.

There is no force to the argument that tariffs and other barriers to commerce can be abolished by the establishment of a federal state They are really weapons of the economic warfare between the ruling groups in a modern industrial state The powerful interests which depend on these restrictions for their prosperity, for example, in the United States, will not consent at the behest of the federal state to lay their industry bare to foreign competition Differences in labor costs alone show the impossibility of this Pritt reminds us of the difficulties caused by the color bars at Versailles, although it is not quite clear just why he blames this on the rich

The plan for the federal legislature rests, Pritt thinks, on two false assumptions (1) That elections can be taken at their face value without investigating the conditions under which they are carried on It is notorious that many ostensibly democratic elections are fictitious and dishonest Wealth controls The results would be even more warped in dictatorships and undeveloped countries The ruling interests of different nations would merely carry their fatal rivalries into the new legislature (2) It is assumed that all states in the federation are equal This completely ignores the distinction between great powers, small powers, and client states under the influence of the great powers

Then comes a sharp thrust Streit's proposed Union is not really a world union, but limited to fifteen states It is the preliminary syndicate and not the operating company Many states are still left outside to fight It excludes China, the East Indies, and Russia, which make up half the human race Indeed, if we disregard small states and client states, the so-called world union comprises only Great Britain, the United States, and France It is just like the proposed abortive alliance of 1918 and merely revives the Versailles grouping in place of the Four-Power Pact at Munich The omission of Russia is extraordinary because it is the biggest example of a federated union, the most modern and the most thoroughgoing Yet its constitution is wholly ignored as a model It is more democratic than France where women cannot vote, or South Africa where the majority of adults cannot vote, or the United States where Negroes have been practically disqualified It treats the Jews better than do other countries Russia is a democracy where people manage affairs in industry as well as in strict politics So Pritt reprints the Soviet Constitution

in his book as an illustrative substitute for Streit's revamped American constitution.

Russia proves that a federation of socialist republics is easy, whereas a federation of capitalist countries would at most amount to a Holy Alliance of a few powers and their satellite states Some republics came into the Russian federation on their own initiative, but the capitalist states within the former Russian area showed no disposition to enter and would not have been welcomed A socialist country is unified while a capitalist country is split into hostile sections Colonial problems are not met by Streit's union, for it omits India and puts other dependencies under control So likewise, the United States of Europe is bound to turn into a joint plan for the plunder of the colonies But in a socialist federation colonies become people with equal rights

If the Union be made broad enough to include Russia and other omitted countries, states which are so different cannot achieve Dicey's requisite of a feeling in favor of uniting, either for sentiment or for industrial and commercial interests It would be impossible to federate effectively without eliminating conflicts between wealthy groups, and only socialism permits this Consider the difficulties of an attempt to allocate markets for cotton goods between manufacturers in Great Britain and Japan The old conflicts of interest will remain in the member nations which are not socialistic, such as restricting production to keep up prices, oil and wheat, desire for expansion, unemployment, wealth, and poverty. Union is a smoke-screen for the reactionary war aims of British and French ruling classes

It is true that a real federation greatly reduces the danger of war This is not because the states are federated, but because the very connections between them which led them to federate also reduce quarrels and frictions to small proportions Federation and friendship are not cause and effect, but effects of the same causes The attempted federation of groups of states with no real inclination toward union contains no genuine peacemaking qualities It will solve none of the real problems

However, socialism removes the real causes of war Countries which have abolished capitalism then have a strong common interest and a freedom from conflicts which facilitate union, as in Russia The U S S R, Pritt concludes, must be our model.

This completes my survey of four post-war schemes One more book is worth mentioning, although it proposes no scheme This is a pamphlet issued by the Carnegie Endowment for International Peace, entitled "Preliminary Report and Monographs of the Commission to Study the Organization of Peace" It appears as International Conciliation No. 369, for April, 1941 This is written by many different experts Each gives a brief but meaty account of some difficult problem of international organization I have found this the most helpful of all the books I have consulted.

Conclusions

A few remarks of my own may be ventured about these four schemes I find it easiest to start with Mr Pritt and work backwards

The plan for a Union open only to socialist states seems to me the least promising of all the schemes To begin with, the U S S R is the only nation now able to pass the admissions-test, so that great internal changes must take place in Great Britain, Canada, the United States, China, France, and several other countries before the new world federation can be formed Even a European federation must be put off until the same drastic process has taken place on a smaller scale All this offers a gloomy prospect for peace during our lives or our children's lives The establishment of socialism in Russia was accompanied by a long civil war and followed by a good deal more bloodshed for political and economic reasons If, as Mr Pritt contends, there are no conflicting interests inside a socialist state, this harmony may not be due to the inherent capacity of such a régime to produce a persuasive unification of human desires, but merely to the elimination of everybody who ventures to disagree with the people in power Similar civil wars and purges may very well occur in the United States and the countries of western Europe before they are fit to form an international socialist Union As I am one of those who would doubtless be liquidated, it takes more self-sacrifice than I possess to view with equanimity this cheerful sequel to World War II Even if dissentients are allowed to emigrate or slip away, they will have to live somewhere, and they will tend to increase opposition to the federation wherever they go When the longed-for second Armistice has at last arrived, will there be no practicable road to world peace except through a long series of violent revolutions, mass exiles, and massacres?

Of course, it is possible that the present war will produce such extensive expropriation of private property that every state will be virtually socialistic when it ends Then the nations may be able

to slide into a socialist Union without any preliminary turmoil Even so, it is rash to assume that socialism will automatically end war Mr Pritt argues that the inhabitants of a socialist state will not be aggressive because their government will produce all they need This seems inconsistent with the occurrence of several great famines in Russia Political and economic equality will not produce world-wide geographic equality Even without rich men, there will be rich lands The inhabitants of a fertile region may decline to stint themselves drastically in order to feed a famine-stricken state, and so the underfed people may surge outward into the golden wheatfields and green pastures of neighboring states

> "The mountain sheep are sweeter,
> But the valley sheep are fatter,
> We therefore deemed it meeter
> To carry off the latter"

Even if your government gives you all you want now, this does not prevent you from wanting still more and perhaps persuading your government to find it beyond the frontiers The disappearance of capitalism will remove some of the present causes of war, but others will still remain In the present combat between Germany and Russia, both sides call themselves socialists, and certainly there is very little opportunity for private profits in either country Future wars may result from conflicts of interest between different races or regions, between rice-eaters and meat-eaters, between clever people and plodders

In order to adjust such conflicts peaceably, we shall need a more complex scheme than the constitution of the U S S R In spite of Mr Pritt's praise, this does not offer a close parallel to a federation of Europe or the world One of its member-states, Russia, contains three quarters of the area of the U S S R and two-thirds of the population Under such conditions, one partner is likely to be predominant and the rest satellites Even if such a system has worked satisfactorily within the Soviet Union, this tells us very little about the probable success of a greatly expanded socialist federation with several approximately equal large members So if we proposed to set up an organization including, say, Great Britain, the Dominions, the United States, Germany, the U S S R, China, and Japan, then even though they have all become socialistic states, still we shall have to draw on schemes like those of Lord Davies, Streit, and Bingham, in order to determine the best form of organization.

Our next question is, should the world unite in some way or other, or only Europe? It is significant that Mr Pritt's telling objections to a proposal of federalism for the world are much weakened when applied to Europe Here is a body of countries which have belonged for centuries to an intellectual and spiritual confederation, which form an economic unit, whose boundaries have lately become less important There is sufficient likeness and pressure in this crisis to foster a desire for union, sufficient divergence in language and traditions to make them stop short of complete unity A respect for law is strong in western Europe at least, and even the Balkans are probably not more lawless than our frontier states a century ago

On the other hand, a union of Europe alone presents serious perplexities Great Britain seems an essential member, but what are you going to do with the British Empire? If you bring in Russia, half of Asia comes in too, but her omission leaves her a potential disputer with definite interests in the Baltic and the Balkans Non-European dependencies ought to be run by a world organization, not just European, if they are to be administered for their natives and their raw materials handled for the benefit of consumers everywhere

In short, a European union seems feasible, and it will be desirable if it be subsidiary to some sort of world organization

Finally, League or Union? Here I feel still more cautious, but I shall throw out a few ideas for what they are worth I began my reading with a strong feeling that the League had hopelessly failed, and that Grenville Clark's plan of Union, which I already knew, was a better way out The more I have read, the more I have found myself swinging toward something based on the League With all its timidities (which Congress can often imitate) and its defects, the record of unspectacular achievement is much more impressive than I realized The so-called technical services, in particular—health, labor, etc —must not be abandoned Perhaps they could be merely transferred to Mr Streit's Union, but there is more to it than that

In the first place, it is not fair to balance against a League with bad failures a Union with no failures The Union never existed We do not know what it would do My guess is that Mr Streit's Congress might have hesitated about sanctions against Italy in 1935 as much as the Council did, and applied them no better if it lacked an international police. I also surmise that the elected

representatives from Italy or Germany in a Congress would have been *alter egos* of Mussolini and Hitler as much as their appointed delegates to Council or Assembly A dictator can control elections easily, at least if there is no effective federal supervision, and would that have been likely?

Next, the League is a going concern, or at worst was such until Munich You have something to start from You know its weak points so as to remedy them Its strong points have been operating for two decades At least, we should be rather slow to junk it for something entirely new

The parallel with our own Confederation and Union is tempting, but is it sound? American conditions were far more favorable to Union than are world conditions Large areas lie outside a common tradition, and others have not developed a respect for law as we know it A looser form of association may be appropriate, at least for some decades

The failures of the League are not necessarily due to its structure Causes hampered it which may not be repeated There was its entanglement with a dictated peace—this time we may negotiate, especially if the dictators are previously replaced by democratic governments The strains in the early years were terrific Would the United States have survived if the Dred Scott case, secession, the recent depression, and several state dictators like Huey Long had all come within two decades after 1789? The League had to go through all that Our Union had sixty years to become rooted before the first great strain of 1850 Finally, the League may not have worked because its members did not want very much to make it work Rappard in his "Quest of Peace" (March 1, 1940) writes.

> "The nations which had been at war with each other had never concluded a real peace in that they had never succeeded in regaining each other's confidence Those who had won the World War and settled the terms of peace were unwilling to prolong those efforts and to exert their influence to insure the maintenance of those terms The present plight of Europe is due less to the excessive ambitions of the men of 1919 than to the excessive debility of their successors"

It seems possible then that we shall be wise to begin with what we have, the League of Nations It will be wise to use its experience of twenty years with legislative sessions, executive sessions, a judicial tribunal, and numerous administrative bodies of high quality Knowing what were the mistakes of the League, we have some ideas what to avoid This may require drastic changes in the Covenant, and very likely some of these changes may approximate ideas suggested by Streit's Union and other schemes For example, the League finances would be on a sounder basis if the contributions from member states were supplemented by some kind of League tax This might conceivably be levied on all international movements of goods, money, and persons

Getting away from details to a broad outlook on the problem of post-war international organization, the previous discussion suggests two points for the future

In the first place, it is very important to avoid strains during the early years of the new international body Whatever our impulses, there will be no time for vengeance The world after the armistice will resemble a town which has to rebuild itself after a flood The incompetents must be removed, but any other sort of punishment will be a luxury which we cannot afford There will be too much else to do The lesson of our own Reconstruction Period and Europe since November 11, 1918, is, then when a war is over, it ought to be over Briand's words "Pour nous, c'est fini" ought to be spoken on the day of the armistice and not eight years afterwards What I mean can best be illustrated by a letter from an English girl who has lived for two years in constant danger from air-raids It was written on December 14, 1941.

> "Last night I heard on the wireless an excellent 'American Commentary' by Raymond Gram Swing, which traced the course of American public opinion during this first week He described the U S as a nation at first staggered with rage and shame but quickly recovering and now steadily determined But there is, I think, yet another quality of mind in addition to courage and resolution and self-sacrifice that is even harder to acquire and maintain, but which is essential if the war and the peace are to be won This is a certain gentleness—the negation of spite or anger or antipathy to the German people I don't know how to describe it It is well shown in Aeschylus' play 'The Persians' written to celebrate the brilliant victory of democratic Greece over the great totalitarian Persian empire It contains no noisy self-congratulation or boasting pride, but depicts the sorrow of the relatives of the Persian dead. To be dignified in victory is very hard How I hope that both Britain and the United States will maintain till the end of the war the quiet sanity of Athens after Salamis, the reasoned strength and belief in the future"

Another way to avoid strains is the immediate freeing of economic life after the armistice, so as to produce on both sides a feeling of great relief that the war is ended This time there must be no food blockade.

Also, there must be no raids, like those on Vilna and Fiume No matter what the costs, those in charge of the peace must make everybody realize that fighting has got to stop Perhaps frictions could be reduced by establishing a temporary *status quo*, say for twenty-five years, with a definite method for later adjustments

Strains can be reduced by the restoration of normal life through rapid reconstruction on a great scale International understanding might be increased if this were carried out cooperatively For example, suppose some German workmen came over to help in England and *vice versa* Each visiting group would soon realize that people very much like themselves had suffered in a common disaster Who will pay for this vast work of reconstruction? The answer is simple, though perhaps unpalatable Who pays for the war? For the most part, we do I suspect that we must also bear a heavy share of the expense of reconstruction in order to avoid an infinitely greater outlay in preparation against a Third World War

Secondly, no scheme is enough The spirit is even more essential Years ago André Siegfried remarked to me that the League of Nations lacked "Geist" It had no personality To the ordinary man it was just a distant piece of machinery in Geneva One strong reason for the success of the United States in the early years was that the nation was immediately brought before the eyes of every citizen through flags over post-offices, federal judges and officials in every state, naval vessels in harbors, and the government stamp on coins In some such way, the new international body must become a reality for the common man everywhere It would be very helpful if the League could fly its flag widely and take over a considerable number of everyday things like postage stamps and coinage The League symbol should be put on all the great public works built during reconstruction Its officials and benefits should be made generally visible Recreation is an excellent way to make the League a drawing force It might take over all youth hostels, which formed one of our most hopeful international organizations before the war It might arrange international excursions at public expense, taking a leaf from the book of the Nazis and using these excursions for mutual understanding instead of nationalistic pride

The spirit is all important The new international organization requires a desire to make it work as well as a desire to start it In this respect practically all the books I have read are at fault They possess little emotional appeal They lack the quality which shone so clearly in the speeches of Woodrow Wilson We must make people everywhere want to join a world organization

Some such organization must come into existence, for the alternative of perpetual defense and repeated total warfare is hideous Still we must not minimize the difficulties When the local contractor in the little Maine village where we go for the summer engages workmen from the next village, there is an outcry against the employment of "foreigners" This illustrates the frictions which must be overcome between inhabitants of different countries and different parts of the world There is no simple solution We must be patient and remember that cathedrals are rarely built by a single generation We must know much—we must hope much

[1] Matthew Arnold, introduction to *Poems of Wordsworth* (Golden Treasury edition) vii (1879)

[2] This account of China is based on Owen Lattimore, *Inner Asian Frontiers of China*, 339–406, 419–425, 444–447 (1940)

[3] Joint Resolution of June 25, 1910, 36 Stat 885

[4] See Carl Becker, "Making Democracy Safe in the World" 31 Yale Review 433 (1942)

[5] 55 Harv L Rev 561

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THE LOWER PERMIAN INSECTS OF KANSAS. PART 9. THE ORDERS NEUROPTERA, RAPHIDIODEA, CALONEURODEA AND PROTORTHOPTERA (PROBNISIDAE), WITH ADDITIONAL PROTODONATA AND MEGASECOPTERA.

BY FRANK M. CARPENTER

THE LOWER PERMIAN INSECTS OF KANSAS. PART 9. THE ORDERS NEUROPTERA, RAPHIDIODEA, CALONEURODEA AND PROTORTHOPTERA (PROBNISIDAE), WITH ADDITIONAL PROTODONATA AND MEGASECOPTERA.*

By Frank M Carpenter

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Dr. Tillyard's sudden death in 1938 left unfinished his account of the Permian insects from the Elmo limestone in the Peabody Museum at Yale University The unstudied specimens in that collection, mostly belonging to the Protorthoptera and related groups, have recently been turned over to me by the authorities of the Peabody Museum for identification and description The present paper deals with the Caloneurodea contained in both the Yale and Harvard Collections, and with the Neuroptera, Raphidiodea, and part of the Protorthoptera (family Probnisidae) in the Harvard collection, the Yale specimens of these groups having already been described by Tillyard I have also included here an account of some Protodonata and Megasecoptera in the Harvard collection which were not considered in my earlier papers on these orders

Additional PROTODONATA

Since the publication of my previous account of the Protodonata from the Elmo limestone (1939), Professor R C Smith, of Kansas State College, has sent me a magnificently preserved hind wing of *Megatypus schucherti* Tillyard (family Meganeuridae). It was collected by two entomological students in the College, Mr Otto Wenger and Mr. Floyd Holmes; the reverse of the fossil is in the Kansas State College entomological collection and the obverse in the Museum of Comparative Zoology

Apart from doubtful fragments, *M schucherti* has previously been known only from the holotype, a hind wing lacking the distal fourth of the wing and some details of venation (Tillyard, 1925) The new specimen is an absolutely complete hind wing, showing with perfect clarity all veins (Plate 1, figure 1). It is not only interesting as the largest entire wing yet found in the Permian, but it is also important because it enables us to complete our knowledge of the venation of this huge insect The new wing is 195 mm long and 40 mm wide (maximum). This indicates that the total wing expanse was about 41 cm or 16 inches The holotype specimen, which was not quite complete, measured 165 mm in length [1]

Tillyard's restoration of the wing of *schucherti* (1925, fig 5) is now seen to be incorrect in two respects First, the wing is more slender apically than he assumed it to be, and second, the subcosta ends well before the apex of the wing, instead of at the apex, as he has drawn it His figure of the actual type specimen is incorrect in that it has R4 + 5 (termed R3 in his paper) arising in the distal half of the wing, well beyond the level of the first fork of MA. Actually, R4 + 5 arises (in both the holotype and the new specimen) slightly before the middle of the wing, and directly above the fork of MA In all except individual details the new wing has the same venation as the holotype

One of the most interesting aspects of the new fossil is the presence of an oblique vein at the point of separation of R2 from R3 This is obviously the homologue of the vein (subnodus) described by Sellards in *Typus permianus* (1906, p 253, figs 4, 5) As I have already stated (1939, p 38) such a vein has not previously been discernible in any Protodonata (*Megatypus* or *Typus*) in the Yale or Harvard collections from Elmo It should be noted that there is no indication of the oblique vein "o" described by Sellards in *Typus* The obliquity of this vein is almost certainly an individual trait

Additional MEGASECOPTERA

The extinct order Megasecoptera is not uncommonly represented in certain Carboniferous strata of Europe, but until comparatively recently it has not been found in Permian rocks The insects which Tillyard originally described from the Elmo limestone as members of a new order, Protohymenoptera,

* This investigation has been aided by a grant from the Permanent Science Fund of the American Academy of Arts and Sciences

[1] The width of the holotype wing was given by Tillyard as 94 mm, but this is an error; it should have been 39 mm

are now generally recognized as close relatives of the Megasecoptera and as constituting merely a suborder of the Megasecoptera. In his last discussion of the affinities of the Protohymenoptera, Tillyard (1936) expressed agreement with this view, though claiming it to be a matter of personal choice whether the group be regarded as a suborder or an order. The Protohymenoptera from the Elmo limestone contained in the Harvard collection have already been described (Carpenter, 1931a, 1931b, 1933, 1939).

Apart from the Protohymenoptera, the order Megasecoptera is represented in the limestone by several species which are more closely related to the Eumegasecoptera[1] than to the Protohymenoptera. One of these, *Elmoa trisecta* Tillyard, was recognized by Tillyard as a Megasecopteron and placed by him in a new family, Elmoidae. Two other species which he described from the formation (*Martynovia insignis* and *Martynoviella protohymenoides*) are, in my opinion, also Megasecoptera, though they were considered by him to be Neuroptera, belonging to the suborder Sialoidea (Megaloptera). Unfortunately, not only was each of these three species based upon a single wing, but the type of *Elmoa trisecta* consisted of a basal fragment of a wing Had these specimens been more nearly complete, Tillyard would undoubtedly have recognized the very close relationship between *Elmoa*, which he placed in the Megasecoptera, and the Martynoviidae, which he assigned to the Neuroptera. The evidence for my conclusion on the affinities of these fossils is derived from a study of the specimens in the Harvard collection and will be considered below, after a description of the insects.

Suborder Eumegasecoptera

Family Elmoidae

Wings subequal; membrane glassy. Fore wing. Sc terminating before or at mid-wing; costal veinlets few and weakly developed; Rs arising before mid-wing; M coalesced proximally with R, MA and MP present; MA not coalesced with Rs or R1; CuA coalesced proximally with stem R + M; two anals present, pterostigma apparently absent. Hind wing: narrow basally, but broader near the middle than the fore wing; Sc closer to R than in fore wing; rest of venation as in fore wing. Almost nothing is known of the body structure.

At present the family consists of one genus.

[1] The order Megasecoptera includes the two suborders Eumegasecoptera and Protohymenoptera (Carpenter, 1933).

Genus *Elmoa* Tillyard

Elmoa Tillyard, 1937, Amer. Journ. Sci. **33**: 82.

Fore wing: long and moderately slender; costal space of moderate width, Sc terminating on R1 before mid-wing; R1 unbranched; pterostigma absent or at most very weakly formed; Rs with at least three terminal branches; R, M and CuA separating at the same point; MA probably unbranched; MA joined to Rs by a weak cross-vein shortly after the origin of the latter; MP forked; CuA unbranched; cross-veins few and weakly developed Hind wing: similar to the fore wing in venation, except for differences noted under the account of the family.

Genotype *Elmoa trisecta* Till.

Elmoa trisecta Tillyard

Figure 1

Elmoa trisecta Tillyard, 1937, Amer Journ Sci. **33**: **84**.

Fore wing. length, 12 mm , width, 3 2 mm ; 3 or 4 strong costal veinlets at base, above stem R+M, and 1–3 weaker ones more distal along Sc; a few oblique veinlets between R1 and costal margin, especially distally, Sc terminating beyond origin of Rs, stem R + M arched; R4 + 5 long, arising before mid-point of Rs, R2 and R3 at most half as long as R4 + 5, MA arising proximally to origin of Rs, MP forked to about half its length, CuP not forked, but connected to hind margin by a long cross-vein; 1A remote from hind margin, connected to it by at least one cross-vein, 2A very short.

Hind wing. length, 12 mm., width, 4 mm , more nearly oval than the fore wing; costal space as wide as in fore wing, with similar veinlets, Sc not quite so long as in fore wing and nearer R + M than in fore wing.

The body structure is preserved in one specimen (No. 4591ab); this shows only the thorax, part of the head, and a small piece of the abdomen. The head is small (1 5 mm. long) and broad, and apparently has prominent eyes.

Holotype: No. 15591ab, Peabody Museum, Yale University. This consists of the basal third of a hind wing, not a fore wing, as stated by Tillyard.

In the Harvard collection there are eight specimens of *trisecta*, of which six are from the upper layer of the limestone: no. 4591ab, a complete insect, showing both pairs of wings; the fore wings overlap part of the hind pair, but the two pairs are readily distinguished. No. 4606ab, a very nearly complete fore wing, well preserved; no. 4595ab, 4607ab, each consisting of the proximal third of a fore wing; no 4590ab, a complete and excellently preserved hind

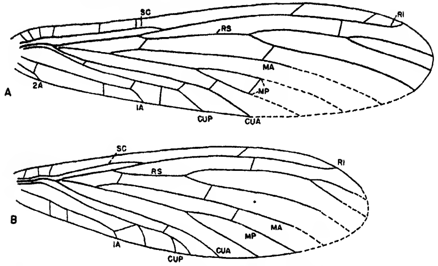

FIGURE 1. *Elmoa trisecta* Till. A, fore wing: drawing based mainly on specimen no 4604, Mus. Comp Zool. B, hind wing; drawing based chiefly on specimen no. 4590, Mus Comp Zool. Sc, subcosta (concave); R1, radius (convex); Rs, radial sector (concave); MA, anterior media (convex); MP, posterior media (concave); CuA, anterior cubitus (convex); CuP, posterior cubitus (concave); 1A, 2A, anal veins

wing, and nos. 4592ab, 4593, 4594ab, all hind wings, more or less complete These specimens were collected by F M. Carpenter at the Harvard quarries at Elmo

Tillyard's figure of the base of the hind wing of this species (1937, fig 1) is incorrect in two important respects The subcosta terminates on R1 just beyond the origin of Rs, instead of continuing for a considerable distance beyond this point, as he has drawn it. The wings of nearly all specimens of *trisecta* are wrinkled (as in the Protohymenoptera of the Elmo limestone) and apparently one of these wrinkles was confused by him with the end of Sc. He has also drawn MA as forked shortly beyond its origin; but this fork does not show in the type specimen or in any of the fossils in the Museum of Comparative Zoology In none of the specimens of *trisecta* which have been found is MA preserved to the actual wing margin, but the missing part is so short that it seems almost certain that this vein was unbranched.

THE AFFINITIES OF THE ELMOIDAE

Although *Elmoa* possesses a number of characteristics foreign to the Carboniferous and most Permian Megasecoptera, I believe with Tillyard that it belongs to this order. All of the Eumegasecoptera previously known have possessed a petiolate or subpetiolate wing. The relatively broad wing base of *Elmoa* therefore suggests that the family which it represents was more generalized than other known Megasecoptera As Tillyard has proposed, the Elmoidae were probably Permian derivitives of a group of Megasecoptera which must have existed well back in the Pennsylvanian Period The short subcosta of *Elmoa*, however, is a specialization not previously found in any Eumegasecopteron, though a similar subcosta occurs in the Protohymenoptera.

Of particular interest in connection with the affinities of *Elmoa* is the difference in the shape of the fore and hind wings The complete specimen in the Harvard collection shows conclusively that the broader wing is the hind one This is consistent with the condition which occurs frequently throughout the Megasecoptera as a whole, including such slender winged types as *Foriria maculata* Meunier, from the Carboniferous of Commentry.

So far as the Permian is concerned the following family, Martynoviidae, seems to be the one most closely related to the Elmoidae.

Family MARTYNOVIIDAE

Wings subequal; membrane glassy. Fore wing: Sc terminating on Rl at about mid-wing; costal veinlets few in number; pterostigma weak, but extensive, the area between R and the costal margin beyond the end of Sc being slightly thickened and pigmented; Rs arising before mid-wing; M coalesced basally with R; MA and MP present, MA coalesced with Rs; Cu coalesced with R + M basally; two or

three anal veins present. Hind wing much broader than the fore wing, costal space slightly broader than that of fore wing; venation like that of the fore wing, except that the pterostigma is absent or very weakly formed at most. The body structure is unknown.

This family was originally established by Tillyard (1932) for two genera, *Martynovia* and *Martynoviella* In a later paper (1937) he also placed here the genus *Promartynovia*, based upon a single wing fragment (*venicosta* Till) Better and more nearly complete specimens of the latter species in the Harvard collection convince me that *Promartynovia* is really a Protorthopteron Tillyard himself suggested that the precostal area in *Promartynovia* was probably a remnant of a formation carried over from a Protoblattoid ancestor The genus *Promartynovia* will accordingly be considered in the following part of this series of papers

For reasons which will be given below, I consider the genus *Martynoviella* to be synonymous with *Martynovia*, which thus becomes the only known genus in the family

Genus *Martynovia* Tillyard

Martynovia Tillyard, 1932, Amer Journ Sci **23**: 13
Martynoviella Tillyard, 1932, ibid , **23**: 17

Fore wing long and moderately slender, costal space of moderate width basally, but narrowed above the origin of Rs; R1 close to the costal margin distally, unbranched; Rs with from 3–5 terminal branches; M separating from stem R + M at about the point of divergence of CuA from R + M; MA, MP, CuA and anals unbranched, cross-veins few in number Hind wing similar to the fore wing, except for differences noted under the family.

Genotype *Martynovia insignis* Till.

At present two species of this genus are known, *insignis* Till. and *protohymenoides* Till. The latter is the genotype of *Martynoviella*, which I have synonymized here with *Martynovia*. In regarding these two species as representatives of different genera, Tillyard was unaware that one of them (*insignis*) was based on a hind wing, and the other on a fore wing Although cognizant of the similarity of their venation, Tillyard was led to place them in separate genera by the difference in wing shape Actually, of course, this difference is due to the fact that the fossils do not represent homologous wings.

Martynovia insignis Tillyard

Figure 2

Martynovia insignis Tillyard, 1932, Amer. Journ Sci **23**: 15

Fore wing. length, 12 5–20 mm ; width, 3–4 7 mm Costal margin arched basally, slightly concave just beyond the origin of Rs; costal space broad basally,

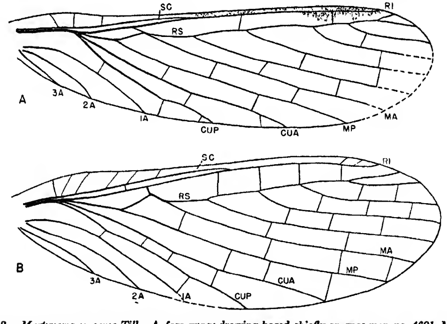

FIGURE 2 *Martynovia insignis* Till A, fore wing; drawing based chiefly on specimen no. 4601, Mus. Comp. Zool B, hind wing; drawing based mainly on specimen no 4604, Mus. Comp. Zool , and the holotype. Lettering as in figure 1

but very narrow before end of Sc; several prominent costal veinlets; Rs with from 4–5 branches; usually two cross-veins between each of these and MA and MP; CuA and CuP separating at about the same level as the point of divergence of Rs from M; 1A and 2A well developed; 3A sometimes present near base of wing. Cross-veins strongly developed. Hind wing length, 12.5–20 mm ; width, 4 2–6 mm Costal area broader than in fore wing and not so markedly concave, venation as in the fore wing. The hind wing appears to lack a pterostigma; its absence in the holotype (hind wing) can hardly be due to its failure to be preserved, since the wing is in excellent condition

Holotype. no. 5423, Peabody Museum, Yale University. This is a hind wing, not a fore wing, as stated by Tillyard

In the Harvard collection there are three specimens of this insect, all from the upper layer of the limestone and collected at Elmo by F. M Carpenter no 4600ab, and no 4601ab, complete and well preserved fore wings, and no 4604ab, a hind wing, about two-thirds complete, lacking only a part of the costal area and most of the actual posterior margin

Tillyard's drawing of the wing of *insignis* (1932, fig 5) is incorrect in two important respects in the first place, the "obsolescent costal vein" which he represents in solid lines in one illustration (fig 5) and in dotted lines in another (fig 6), does not exist in the type nor is it present in the Harvard specimens. Tillyard himself was apparently doubtful of its presence, for he states (p 16) that he was unable to satisfy himself of the course of this vein Such a vein does not occur in the Megasecoptera, though it is found in many Neuroptera In the second place, the "obsolescent Cu2," represented in his figure by dotted lines, is also not present in any of the specimens, including the type. Of this vein he states that he could not be quite certain even of its existence I am at a loss to explain why Tillyard did not recognize as CuP (Cu2) the vein which he has designated Cu1b, this is concave, as CuP should be, and it occupies the normal position of this vein.

Since no complete specimens of *insignis* or *protohymenoides* are known, I have based my conclusion on the identity of fore and hind wings of these two species on comparisons with the wings of *Elmoa*. It is at once clear from an examination of the two wings shown in figure 2 that their venation is identical, the only differences between them being in wing shape. Two possible interpretations of these wings can be made, they might represent two species of *Martynovia*, one slender and the other broad; or they might be fore and hind wings of the same species. The latter interpretation is the one which seems certainly correct, in view of the wing structure of *Elmoa*, the fore and hind wings of which show the same differences as those existing between the wings in figure 2 Furthermore, it is also apparent from the condition in *Elmoa* and other Megasecoptera that the broader of the two wings is the hind one

[3] Martynov (1938b, p. 39), without having seen any specimens of Martynoviidae, suggested on the basis of the published figures that Tillyard's Cu1b (CuA2) was really CuP.

Martynovia protohymenoides (Tillyard)

Figure 3

Martynoviella protohymenoides Tillyard, 1932, Amer Journ Sci **23**: 18.

Fore wing length, 12.5–17 mm., width, 3–3 5 mm ; much more slender than that of *insignis;* costal margin only slightly arched basally and almost straight beyond this part; costal space not narrowed until about mid-wing; pterostigma as in *insignis* though not extending so far proximally, Sc more remote from R1 than in *insignis*, costal veinlets and other cross-veins apparently fewer in number than in *insignis;* Rs with 3–4 branches; CuP separating from R + M much further proximally than the point of separation of CuA, 3A is not preserved in any specimen, cross-veins very weak Hind wing unknown.

Holotype. No. 5424, Peabody Museum, Yale University This consists of a nearly complete fore wing, only about the proximal fifth of the wing is missing.

In the Harvard collection there are three specimens of *protohymenoides*, all from the lower layer of the limestone and collected by F M Carpenter. no 4597ab, the distal half of a fore wing; no. 4599ab, a complete and well preserved fore wing; and no. 4558ab, a nearly complete fore wing.

This insect is obviously very similar to *insignis* and differs from it in such minor characteristics as the shape of the wing and of the costal space. In separating *protohymenoides* from *insignis* generically, Tillyard was misled by the fact that he had only the fore wing of one species and the hind wing of the other His figure of the type of *protohymenoides* (1932, fig. 7) is not entirely correct. He has drawn more of the proximal part of the wing than is actually preserved and his restoration of the base of the wing does not agree with the structure shown in the Harvard specimens. The pterostigma is faintly but

clearly indicated in the holotype, though it is not mentioned by Tillyard. It is more distinctly preserved in one of the Harvard specimens (no. 4598).

The Affinities of the Martynoviidae

As previously mentioned, the family Martynoviidae was placed by Tillyard in the suborder Sialoidea of the order Neuroptera. Unfortunately, Tillyard gives no reasons for his decision that *Martynovia* and *Martynoviella* were Neuropterous, apparently assuming that their systematic position was obvious. However, in his discussion of the phylogenetic relationship between the Martynoviidae and the existing Sialoidea, Tillyard concluded that the Martynoviidae were in no sense ancestral to any Recent members of the order Apparently, therefore, he recognized the existence of great differences between the living Sialoidea and the Martynoviidae. He explained these differences by the assumption that the Martynoviidae were an end group of Neuroptera which arose from Carboniferous stock. In my opinion, however, the differences are simply due to the fact that the Martynoviidae are not at all related to the Neuroptera or to any other holometabolous insects.

A comparison of the wings of the Martynoviidae with those of the Megaloptera shows that whatever resemblances exist (such as the branching of Rs) are entirely superficial; whereas the numerous differences are of a more fundamental type. The short subcosta of the Martynoviidae, for example, is in direct contrast to the long one characteristic of the Megaloptera (Sialoidea), in which the distal part of the subcosta is always associated with the radius in the pterostigmal region. Another essential difference is the presence of the extensive and thickened pterostigma in the Martynoviidae; no such structure is present in the Sialoidea. Without enumerating further differences of this sort, we may conclude, I believe, that the Martynoviidae do not belong with the Neuroptera and have no relationship with them. This view has already been expressed by Martynov (1938b), though he did not present reasons for his conclusion.

We are next faced with the problem of determining the true affinities of the Martynoviidae. Of the Permian insects now known the Elmoidae seem to be the closest to them, in wing structure, at least. All of the main veins have similar origins in both groups, and the short subcosta occurs in both. The chief differences between them are in the coalescence of MA and Rs and the presence of a pterostigma in the Martynoviidae, in the Elmoidae MA is free from Rs and a true pterostigma is apparently absent. However, these two characteristics are the ones *which distinguish the Elmoidae from the other known families of Megasecoptera* Consequently, the Martynoviidae are intermediate in wing structure between the Elmoidae and certain other Megasecoptera It is my conviction, therefore, that the Martynoviidae are Megasecopterous, belonging to the suborder Eumegasecoptera, and that their systematic position is not far from that held by the Elmoidae.

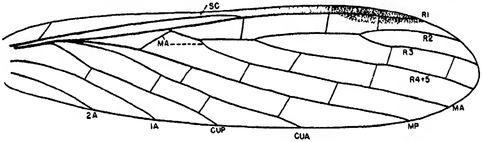

Figure 3 *Martynovia protohymenoides* Till. Drawing of fore wing, based chiefly on specimen no 4599, Mus. Comp Zool. Lettering as in figure 1.

The pterostigma of the Martynoviidae is of much interest in this connection. As already noted, this pterostigma, although only slightly thickened, is very suggestive of that in the suborder Protohymenoptera (Megasecoptera). In the latter insects, the area between R1 and the costal margin is thickened and pigmented for a considerable distance. I do not believe, however, that the similarity of the pterostigma in these two groups is sufficient to justify the reference of the Martynoviidae to the Protohymenoptera, for they have much more in common with the Eumegasecoptera. Nevertheless, they were probably not far from the line which gave rise to the Protohymenoptera. Incidentally, I wish

to point out that although no true pterostigma has been seen in the wings of the Carboniferous Megasecoptera, one might well have been present; all or nearly all of the Carboniferous species are preserved in black or very dark gray shale, in which such detailed structures as a pterostigma are obscured.

Tillyard was obviously aware of the similarity between the Martynoviidae and the Protohymenoptera, for he says of *Martynoviella* (1932, p 23): "There is here, surely, something more than a purely chance resemblance to Protohymenoptera While it can scarcely be doubted that this genus is Sialoid, the strongly formed veins and cross-veins, with the obsolescent chaetotaxy, the general scheme of venation and the curious arrangement of the cross-veins, strongly suggest the possibility of an affinity between the two orders And if, as may be possible (though I cannot accept Carpenter's supposed proof of it, of which more later) the Protohymenoptera are descended from Megasecoptera, then we may also have to reconsider Handlirsch's view that the Neuroptera are similarly derived" The latter part of this statement is of much interest, since four years later (1936) Tillyard accepted in full the thesis that the Protohymenoptera were Megasecopterous (1936, p 450) I do not for a moment believe, however, that we are thus obliged to give serious consideration to the derivation of the Neuroptera from such highly specialized insects as the Megasecoptera As Tillyard himself pointed out (1932, p 29), if there is one thing that appears certain it is that the two orders Mecoptera and Neuroptera have come from a common stem, and that this type must have combined in itself the more archaic characteristics of both the Meropoidea (Mecoptera) and Sialoidea Such an ancestor is almost certain to be found among the Orthopteroids (probably Protorthoptera), not among the Megasecoptera

Martynov (1938b), who has expressed doubt of the Neuropterous affinities of the Martynoviidae, has suggested that the family might be allied to the Archodonata, an order established by him for certain Permian insects related to the Odonata The additional fossils described in the present paper, however, appear to eliminate this view, which was in fact proposed by him merely as a possibility, pending the study of further specimens of Martynoviidae

Order NEUROPTERA

The order Neuroptera is very sparsely represented in the Elmo limestone There are but two specimens unquestionably referable to this order in the Yale collection and only nine in the Harvard collection These eleven specimens are of much significance, however, since they constitute the earliest geological record of the order

It is a fact well known to entomologists that because of their great diversity of structure the Neuroptera defy a concise definition Even the wing venation in the order is of such a bewildering variety that taxonomists have found it impossible to draw up venational limits of the group This diversity of venation leads to a serious problem in the case of the fossil Neuroptera, of which only the wings are usually preserved At least some uncertainty necessarily attends the determination of isolated wings as Neuroptera, especially specimens from Palaeozoic strata. I emphasize this here because I am convinced that several of the insects from the Elmo limestone which Tillyard has described as Neuroptera are not even related to the order, and consequently that the conclusions which he has based on these specimens are not valid

Four of the Neuroptera which Tillyard described from the Yale collection were placed by him in the suborder Planipennia (Neuroptera, s s) and four others in the suborder Sialoidea (Megaloptera). The following list includes all of these insects

Suborder PLANIPENNIA
  Fam PERMOBEROTHIDAE
    Permoberotha villosa Till (1932)
    Permoberotha convergens Till (1937)
    Dictyobiella nervosa Till (1937)
    Permobiella perspicua Till (1937)
Suborder MEGALOPTERA (Sialoidea)
  Fam Choristosialidae
    Choristosialis enigmatica Till (1932)
  Fam Martynoviidae
    Martynovia insignis Till (1932)
    Martynoviella protohymenoides Till (1932)
    Promartynovia venicosta Till. (1937)

A study of both Yale and Harvard specimens of these species has convinced me that none of those described as Sialoids are really Neuropterous The genera *Martynovia* and *Martynoviella* belong, in my opinion, to the order Megasecoptera, the reasons for this conviction have already been given above, in the account of additional Megasecoptera The genus *Promartynovia*, which was based upon a small fragment of a wing, is clearly Orthopteroid, the evidence for this conclusion has been obtained from several complete wings in the Harvard collection and will be discussed in the subsequent paper in this series. *Choristosialis* should, I believe, be regarded as Mecopterous until evidence to the contrary has been found The unique specimen on which the genus

was established consists of less than half of one wing. Tillyard himself expressed some doubt of the Neuropterous affinities of this insect, pointing out that it had certain Mecopterous features, such as the dichotomous branching of Rs and M. The latter seems to me to have far more significance than the presence of possible Sialoid characteristics, such as the costal veinlets, which incidentally are also present in the generalized Mecoptera (suborder Protomecoptera) If *Choristosialis* were regarded as a Sialoid, it would be the only representative of the group in the Lower Permian, hence, in view of the incompleteness of the type specimen and the unquestionable existence of true Mecoptera in the Lower Permian, I prefer to consider it a Mecopteron.

Of the insects which Tillyard described as Planipennia, *Permobiella* is beyond doubt, as already shown by Martynov (1938a, 1938b), a relative of the Orthopteroid family Caloneuridae, recently placed by him in a new order, Caloneurodea My account of this genus, with descriptions of related genera, will be found below under that order The family Permoberothidae, however, almost certainly belongs to the Planipennia. Only one valid species of this family, *Permoberotha villosa* Till, has so far been found in the Elmo limestone, and if its affinities have been correctly determined, it is the oldest record of the order Neuroptera.

The venational terminology used in the following account of the Permoberothidae requires an explanation In 1928 and again in 1932 Martynov expressed his conviction that the vein previously identified as the media in most existing Neuroptera was in reality only a posterior branch of the media (i. e, MP), and that the anterior branch had been identified as part of the radial sector. Tillyard in his first paper on the Neuroptera of the Elmo limestone (1922) accepted this interpretation and attempted to apply it to *Permoberotha* The lettering of the veins in his drawing of the wing follows this terminology, but through some oversight his description of the venation in the text gives a different interpretation, more nearly following that of Comstock (1918) In his second paper (1937) on the Neuroptera of the Elmo limestone, Tillyard rejected Martynov's interpretation, which he had previously accepted, and returned to Comstock's view, so far as the radial sector and the media were concerned. But he did this *solely* on the evidence (1937, p. 102) which he thought was provided by another Neuropteron from the Elmo deposit, *Permobiella perspicua* Till.; this incomplete wing he believed to be a Planipennian "reduced to its lowest terms." Unfortunately, he was far wrong in his determination of the affinities of *Permobiella*, for, as Martynov has observed (1938a, 1938b), it belongs without doubt to the Caloneuridae, an Orthopteroid family which Tillyard apparently overlooked completely when he described the fossil. Hence, Tillyard's rejection of Martynov's concept of the Neuropterous venation was based on evidence which really did not exist. Since I have found, as indicated elsewhere (1940), that Martynov's interpretation explains very satisfactorily the venation of the existing Neuroptera, I have used it here.

Suborder PLANIPENNIA (Neuroptera, s. s.)

Family PERMOBEROTHIDAE

Wings subequal. Fore wing: costal area broader than in hind wing, Sc terminating on costal margin, a series of costal veinlets connecting it to the anterior margin, pterostigma absent; Rs arising from R near the base of the wing, MA coalesced with Rs for a short distance proximally, then continuing as a nearly straight vein almost to the very apex of the wing, MP coalesced proximally with CuA for a short distance, then continuing close to MA and parallel to it; between MA and MP there is a distinct groove, as in Recent Hemerobiidae and other families of Neuroptera, Cu forking at base into CuA and CuP; CuA coalesced with MP for a short distance; CuA2 arising before the separation of MP from CuA, CuP is a faint but distinct, straight vein. Hind wing: Sc close to R and terminating on R1 not far from mid-wing; Rs arising from R as in fore wing and coalesced with MA for a greater interval than in the fore wing; Rs forked as in the fore wing; MA, MP, CuA and CuP essentially as in the fore wing; groove present between MA and MP.

Little is known of the body structure: the abdomen was slender and terminated in a pair of short cerci.

The family Permoberothidae is so far represented by only one genus.

Genus *Permoberotha* Tillyard.

Permoberotha Tillyard, 1932, Amer. Journ. Sci., **23**: 24; 1937, ibid, **33**: 108

Dictyobiella Tillyard, 1937, ibid., **33**: 104

Fore wing slender; costal area narrow basally, but broadened above the origin of Rs, recurrent humeral vein absent; costal veinlets not forked; Rs forked at about mid-wing or beyond, its branches somewhat zigzagged; CuA1 forked at least once; 2A terminating on 3A. Cross-veins are numerous and not arranged in gradate series. Hind wing: costal space with well developed veinlets; Rs forked as in

the fore wing; 2A terminating on wing margin, cross-veins as numerous as in the fore wing, not in gradate series.

Genotype: *Permoberotha villosa* Tillyard. This is the only species of the genus known at present

Permoberotha villosa Till.

Figure 4

Permoberotha villosa Tillyard, 1932, Amer Journ. Sci., **23**: 25

Permoberotha convergens Tillyard, 1937, ibid., **33**: 109

Dictyobiella nervosa Tillyard, 1937, **33**: 105

Fore wing. length, 9 mm.; width, 2 8 mm. Anterior margin slightly concave; 10–12 costal veinlets, and 7–9 between R1 and the costal margin, a single well developed cross-vein between Sc and R just before the origin of Rs, forking of Rs somewhat variable, in the holotype R2 + 3 and R4 + 5 separate in the distal third of the wing, but in one of the Harvard specimens (No 4605) they separate before mid-wing; in none do either of these branches of Rs apparently divide again; CuA1 shows little variation in forking; in all clearly preserved specimens each main branch of CuA1 forks again at the margin. In the holotype, an incomplete wing, there are about 56 cross-veins, and in the best of the Harvard specimens (No 4605) there are 64 cross-veins The fore wing had well developed macrotrichia on the main veins, their large sockets being visible in all specimens. Microtrichia are discernible on the fore wing of the holotype

Hind wing· length, 8 mm , width, 2 8 mm More oval than fore wing and much broader distally than basally, Sc closer to R1 than to the anterior margin, with about 16 well developed costal veinlets between Sc and the margin, and between R1 and the margin. The branching of Rs and CuA1 shows the same variation as in the fore wing

The body structure of this insect is very incompletely known and is preserved only in the holotype of *Dictyobiella nervosa* (no 15592, in Yale collection). The length of the entire body is 6 5 mm., a little less than that of the fore wing. The abdomen is slender, 4 mm long and 1 mm wide. Very little can be made out of the head and thorax; Tillyard has described the shape of the head, eyes and clypeus from this fossil, but I have been unable to identify these structures The abdomen terminates in a pair of cerci These were not entirely exposed when Tillyard described the insects and are therefore incorrectly depicted in his figure (1937, fig. 9a). They are much longer than he thought and consist of 4 or 5 segments There is no terminal bristle, as drawn by him; the structure which he interpreted as a bristle was an exposed part of the rest of the cercus.

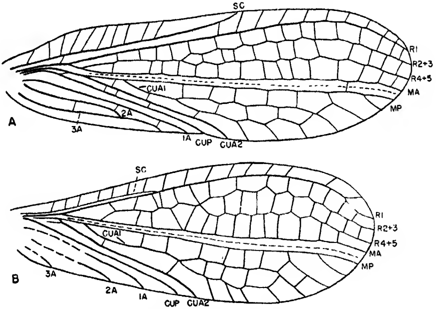

FIGURE 4. *Permoberotha villosa* Till. A, fore wing; drawing based mainly on specimens no 4605, Mus Comp. Zool., and the holotype B, hind wing; drawing based mainly on specimen no 4575, Mus Comp. Zool R2 + 3 and R4 + 5, branches of Rs; other lettering as in figure 1

Holotype No 5426 and its counterpart (15595) Peabody Museum, Yale University

In the Harvard collection there are nine specimens of this insect, nos. 4573–4580 and 4605 Six of these are from the upper layer, four (4572, 4576, 4578, 4579) are hind wings and the rest are fore wings All were collected by F. M Carpenter in the Harvard quarries at Elmo, Kansas, in 1927, 1932 and 1935

Permoberotha convergens Till was based upon the counterpart (obverse) of the holotype of *villosa* This is not readily apparent from Tillyard's figures of these two insects (Tillyard, 1932, fig. 11, 1937, fig. 10), but when I examined the specimens themselves at the Peabody Museum, I was struck by the exact correspondence of cross-veins; and on placing the two fossils together I found that they fitted perfectly Tillyard's figure of the obverse specimen (*convergens*) is very inaccurate and highly diagrammatic. The numerous cross-veins which he shows between CuA, CuP and the anal veins simply do not exist in the fossil.

Dictyobiella nervosa is likewise a synonym of *villosa* Tillyard's figure of its wing does not indicate this, but, as he mentions, his drawing was a composite one, based upon both fore and hind wings The hind wing venation is represented by the short Sc and the fore wing venation by the structure of Rs The cubitus is incorrect for either wing and the zigzagged R4 + 5 (Tillyard's notation) shown in his figure and used for generic diagnosis, does not exist in the specimen In the type specimen of *nervosa* the two fore wings and one hind wing are superimposed so that most of the veins cannot be distinguished, though enough is clear to enable recognition of the venation of *villosa* The second hind wing is preserved out-stretched to one side and its venation is distinct except at the base It is identical with the hind wing shown here in figure 4, except for the position of cross-veins and other individual features Unfortunately Tillyard assumed that the short Sc and other hind wing structures were characteristic of both wings and made them generic. It is noteworthy that *Permoberotha villosa* is the only Permian Neuropteron so far described of which both fore and hind wings are known

Relationships of the Permoberothidae

Since *Permoberotha* is geologically the oldest Neuropteron known, its phylogenetic position is of much interest Tillyard was of the opinion that there was "no valid reason why the genus *Permoberotha* should not be regarded as representative of the ancestral stem of the Berothidae" (1932, p 28). I do not agree with this view. In fact, the difference between the wings of the Berothidae and Permoberothidae are so great I find it difficult to make comparisons. The following summary lists the points of difference between these wings which seem to me to eliminate any possibility of the relationship suggested by Tillyard.

1 *Permoberotha* lacks any sign of a pterostigma. Since a pterostigma of some kind is present in all the Hemerobioidea, including the Berothidae, the absence of it can only be regarded as a specialization—unless of course we consider the very improbable supposition that *Permoberotha* is ancestral to all Hemerobioidea

2. The subcosta of *Permoberotha* terminates at about mid-wing In the Berothidae and all other existing Neuroptera (Planipennia), as far as I am aware, the subcosta terminates nearly at the apex of the wing

3 The radial sector of *Permoberotha* consists of only two branches, in contrast to the multibranched radial sector of the Berothids and nearly all existing Planipennia

4 The branches of Rs and Cu are strongly zigzagged, a specialization which is not found in any Berothid

5. MA is unbranched and close to MP in *Permoberotha*, the proximity of MA and MP is a specialization not known in existing Neuroptera

6 MP in *Permoberotha* is coalesced basally with CuA in both wings, another specialization which is not known to me in existing Planipennia

7 Sc in the hind wing of *Permoberotha* is very short, terminating on Rl well before the middle of the wing, such a structure of Sc is unknown in Recent Neuroptera

These differences have led me to the opinion that the family Permoberothidae is much too highly specialized to be ancestral to the Berothidae, or for that matter to any other existing family of Neuroptera It is more likely a specialized offshoot of a group of Upper Carboniferous Neuroptera, having little phylogenetic relationship with existing members of the order This conclusion is substantiated by a comparison of *Permoberotha* with the Upper Permian Neuroptera which have been described from Russia and Australia (Martynov, 1932; Tillyard, 1926) All of these Upper Permian species, of which seventeen have been described, are far more generalized than *Permoberotha* and show numerous characteristics found in Recent families, such as the Berothidae, Osmylidae, and Psychopsidae. The Permoberothidae are certainly far removed from these other Permian types.

The real significance of *Permoberotha* is not to be

found in the evidence it provides for the relationship or evolution of existing Neuroptera; but (provided it is a Neuropteron) in the evidence it furnishes that the order had been established long enough by the time of the lower Permian to include such highly specialized members

Order RAPHIDIODEA

A single species of Raphidiodea, *Permoraphidia americana*, was described by Tillyard from the Elmo limestone in 1932 This insect is obviously a very rare one in the formation, the holotype is the only specimen of it in the Yale collection and there are but six additional specimens in the Museum of Comparative Zoology An undescribed species of the same genus is also present in the Harvard collection These new fossils fully substantiate Tillyard's conclusion on the affinities of the Permoraphidiidae and add materially to our knowledge of their structure

Family PERMORAPHIDIIDAE

Wings subequal, the membrane lacks microtrichia and apparently macrotrichia, but it is not glassy, as in the existing Raphidiodea Fore-wing. a recurrent humeral vein, resembling that of some Neuroptera, is present; this vein may be a submarginal costa, as it was interpreted by Tillyard Costal veinlets well developed and about as numerous as in Raphidiidae, pterostigma well developed, traversed by several cross-veins, R1 unbranched, Rs arising at about mid-wing, with at least two branches, M coalesced with R basally and with CuAl for a short distance, the free piece of CuA1 before this coalescence being oblique, MA and MP diverging distally to the separation of CuA1 from M, MA coalesced with Rs for a short distance, Cu free from M basally, shortly dividing into CuA and CuP, CuA forking before mid-wing, CuA1 diverging anteriorly and coalescing with M for a short distance, CuP weak, unbranched, 1A, 2A, 3A unbranched, cross-veins more numerous than in Raphidiidae, especially in anal area Hind wing slightly smaller than fore wing and with narrower costal area, recurrent humeral vein absent, venation similar to that of fore wing (anal area unknown).

The family is represented by the single genus *Permoraphidia*

Genus *Permoraphidia* Tillyard

Permoraphidia Tillyard, 1932, Amer. Journ. Sci **23:** 6.

Fore wing. Rs with at least two forks, each having terminal branches; Rs widely separated from R1 and connected to it by several long cross-veins; a well developed cross-vein joins M (or MA) to R1 (or Rs) before the coalescence of MA and Rs, forming a conspicuous triangular or quadrilateral cell Hind wing similar to fore wing, except for the differences already noted

The body structure is unknown

Genotype *Permoraphidia americana* Tillyard.

Permoraphidia americana Tillyard

Figure 5

Permoraphidia americana Tillyard, 1932, Amer. Journ Sci, **23:** 8

Fore wing. length, 9 5–10 5 mm , width, 2 3–2.6 mm , elongate and oval, costal margin only slightly arched, apex somewhat pointed, recurrent humeral vein extending only to about the level of separation of CuA and CuP, with about 6 veinlets between it and the anterior margin, 4–8 costal veinlets, pterostigma rather broad, of uniform density, several subcostal veinlets present, usually four in pterostigma, Rs originating at about mid-wing, the amount of coalescence between Rs and MA is about equal to the length of the free part of Rs before the coalescence, Rs forked to level of middle of pterostigma; both terminal branches of Rs forked again at margin, MA with two or three terminal branches, MP with one or two well developed terminal branches, amount of fusion between M and CuA1 variable, but it is at least equal to the interval of coalescence of Rs and MA, CuA1 forked to about half its length, CuA2 simple, unbranched, 1A close and parallel to CuP, 2A close to 1A proximally, but diverging from it distally, 3A short and close to the posterior margin, between all anal veins is a variable number of cross-veins, mostly curved or sigmoidal. Hind wing all of the hind wing is known except the distal part of CuP and the anal veins The largest fragment is 8 mm long and 2 5 mm wide, in all probability the wing was a little shorter than the fore wing, though about as broad Costal area narrower than in fore wing, Sc terminating as in fore wing, pterostigma slender; Rs arising further proximally than in the fore wing, M forked and coalesced with CuA1 as in fore wing

Holotype. No. 1522ab, Peabody Museum, Yale University.

In the Harvard collection there are six specimens of this insect from the Elmo limestone, three from each layer. no. 4581, a complete fore wing, without distortion and very well preserved, except for the cross-veins; no 4582ab, distal third of a fore wing, well preserved; no. 4584ab and no 4585ab, fore

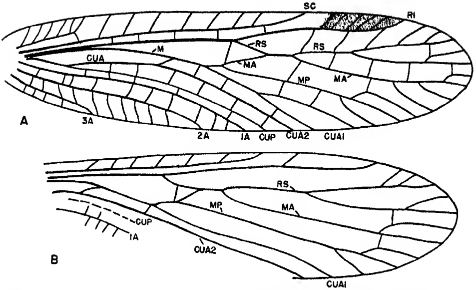

FIGURE 5 *Permoraphidia americana* Till A, fore wing; drawing based mainly on specimens no. 4581 and 4584, Mus Comp Zool B, hind wing; drawing based on specimens no 4586 and 4583, Mus Comp. Zool. M, common stem of MA and MP, other lettering as in figure 1.

wings, incomplete but well preserved, no 4586ab, a hind wing, fairly well preserved, 4583ab, distal third of a hind wing. In the Sellards collection there is one nearly complete fore wing (no 113)

The drawing of the fore wing in figure 5 is based mainly on specimen no 4581, with the addition of some cross-veins shown better in specimen no 4584 It should be noted that Tillyard's figure of the fore wing of *americana* (1932, p 6) is incorrect in several details, such as the structure of the "recurrent humeral vein" (termed the costa by Tillyard) and the proximal part of the posterior wing margin. I have identified two of the fossils (nos 4586, 4583) as hind wings of this species solely on the basis of their venation, no complete specimens of *americana* having been found The wings mentioned have a venation identical with that of the type of *americana*, except for differences which in general occur between the fore and hind wings of existing Raphidiodea.

The wings of *americana* were apparently very delicate This is indicated by the fact that all but one of the eight wings of this insect which have been collected are folded or torn It is most interesting to find this true of *Permoraphidia*, since the wings of the existing Raphidiidae are also fragile Apparently, however, the Permoraphidiid wings were not glassy, as in the Recent members of the order. Such a glassy texture is clearly preserved in the fossils of the Elmo limestone, as in the Megasecoptera and Odonata; but is not even suggested in the specimens of Permoraphidia. Macrotrichia, which are well developed in Recent Raphidiodea, are not preserved in any of the specimens of *americana*.

Permoraphidia grandis, n sp.

Figure 6

Fore wing length of the preserved part of wing, 15 mm , estimated length of entire wing, 17 mm.; width of preserved part of wing, 3 mm ; estimated width of entire wing, 4 mm Costal space much broader basally than in *americana*, recurrent humeral vein also longer than in *americana*, with about ten veinlets leading from it to the costal margin; pterostigma slender, divided into two parts, the anterior part being thicker than the posterior part; Rs forked as in *americana*, MA coalesced with Rs with a short distance; MP and CuA as in *americana*, CuP and anal veins unknown.

Holotype. no. 4589, Museum of Comparative Zoology, collected in Elmo limestone (upper layer) at Elmo, Kansas (F. M. Carpenter).

This insect was obviously a close relative of *americana*, and I have assigned it to the same genus, even though the structure of the hind wings is unknown. It had almost twice the wing expanse of *americana*, and the fore wing was probably much broader than that of the genotype. The most peculiar feature of *grandis* is the pterostigma, the anterior part of which is thick and swollen, whereas

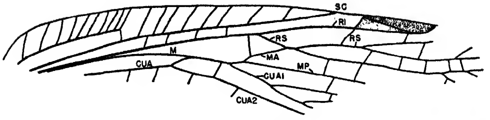

FIGURE 6 *Permoraphidia grandis*, n. sp. Fore wing; drawing based on holotype. Lettering as in figure 5.

the rest, though pigmented, is membraneous, resembling the entire pterostigma of *americana*

THE AFFINITIES OF THE PERMORAPHIDIIDAE

Unlike the Mesozoic and Tertiary genera of Raphidiodea,[4] *Permoraphidia* is decidedly generalized in comparison with the Recent members of the group, and it has a significant bearing on the problem of the interpretation of their venational homologies Martynov suggested over ten years ago (1925) that the anterior media, as well as the posterior media, was present in the existing Raphidiodea The vein which had previously been determined as the most proximal branch of Rs he believed to be the anterior media, which was coalesced proximally with the stem of Rs The evidence for this was derived mainly from analogies with the wings of Neuroptera (Planipennia). The venation of *Permoraphidia*, as Tillyard has shown, fully substantiates Martynov's conclusions In the fore wing of *Permoraphidia* the actual origin of MA and its coalescence with Rs are very clear; so, too, are the origin and coalescence of CuA1 with M. In the hind wing of *Permoraphidia*, which was not known to Tillyard, the structure of MA and CuA1 is practically identical with that of the corresponding veins in the fore wing, except that they originate somewhat nearer the base of the wing, as in the hind wings of existing Raphidiodea. The distinct coalescence of CuA1 with M in the hind wing of *Permoraphidia* is of much interest, for the possibility of such a coalescence in the hind wings of existing Raphidiodea has not previously been suggested. I am now convinced that this coalescence (CuA1 and M) does take place in the Raphidiidae and Inocelliidae An examination of the hind wing of any of the existing genera of snake-flies shows that the vein which I have previously regarded (Carpenter, 1936, fig. 1) as the posterior branch of MP is strongly convex, as CuA1 should be. A comparison of such a wing (Fig. 7) with the hind wing of *Permoraphidia* indicates that the obscurity of the coalescence in the former has resulted from the distal migration of the point of separation of CuA1 from M This migration has progressed so far that CuA1 in existing Raphidiodea is now fused proximally with the base of MP The Jurassic snake-flies (Mesoraphidiidae), it must be admitted, are fully as specialized as the Recent species in this respect, and do not show an intermediate condition, as might be expected.

Although *Permoraphidia* thus aids in the determination of the venational homologies in Recent Raphidiodea, I do not believe that this genus, or the family which it represents, is ancestral to the Mesoraphidiidae, Raphidiidae or Inocellidae. The chief difficulty in the way of such a relationship is the presence of the strong, recurrent vein in the humeral angle of the fore wing This vein was identified by Tillyard as "the last vestiges of a truly archaic costal vein homologous with that in Permian

[4] See Martynov, 1925; Carpenter, 1936

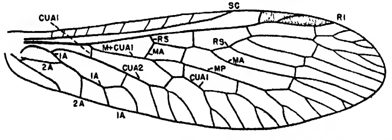

FIGURE 7. Hind wing of *Agulla assimilis* (Alb.) (Recent). Lettering as in figure 5.

Plectoptera." Interpreted in this way, it would be a generalized structure, lost in the subsequent evolution of the order. In my opinion, however, it is more likely the homologue of the "recurrent humeral vein" which is found in many Neuroptera, and which is formed, apparently, by the alignment of several costal veinlets. The absence of the recurrent vein in the hind wing of *Permoraphidia*, as in the Neuroptera, supports this view, rather than Tillyard's, for the submarginal costa (costal brace) of the Permian Plectoptera is as well developed in the hind wing as in the fore. Tillyard's reference to the condition in *Oliarces* is rather puzzling. I have examined the unique specimen by which this genus is known in the Museum of Comparative Zoology, and find that the recurrent vein there is like that of other Planipennia—apparently formed of aligned veinlets. For these reasons, I consider the recurrent humeral vein in the fore wing of *Permoraphidia* to be a specialized, rather than a generalized characteristic.

Order CALONEURODEA

This order was established by Martynov in 1938 (1938a) for a series of fossils formerly placed in the Protorthoptera. The following families were included by him in the new order:

CARBONIFEROUS

Caloneuridae (France, Pennsylvania)
Protokollaridae (France)
Stenaroceridae (France)
? Emphylopteridae (France)

PERMIAN

Euthygrammidae (Russia)
Permobiellidae (Kansas)
Synomaloptilidae (Russia)

In my opinion, the Protokollaridae and Stenaroceridae, both of which were based on single genera, do not belong to the Caloneurodea.[5] The family Emphylopteridae, which was doubtfully included by Martynov in the Caloneurodea, I also exclude from this order. However, in this paper I am erecting three additional families of Caloneurodea: Paleuthygrammidae, Pleisiogrammidae, and Anomalogrammidae. These are established chiefly for species in the Elmo limestone. Although Tillyard described one species of Caloneurodea in the Yale Collection from this formation, he placed it in the Neuroptera. The present paper is therefore the first account of the Caloneurodea as such in the Elmo beds, and it is based upon the specimens contained in both the Yale and Harvard collections.

The characteristics of the order Caloneurodea have been thoroughly discussed by Martynov in a posthumous publication (1938b), but since his paper was printed in Russian, I include here a summary of these characteristics, including several details furnished by the new fossils.

The body structure of the Caloneurodea is only partially known.[6] The head was of moderate size and apparently hypognathous, the antennae were very long and slender, the first antennal segment was large and swollen, the structure of the eyes is unknown. The prothorax was about as long as wide. The abdomen was of moderate size, rather slender, and terminated in a pair of short cerci. The legs were slender, often tenuous, the posterior pair were longer than the others but were not modified for jumping. The tarsal segmentation is unknown.

The fore wings of the Caloneurodea were at least moderately slender and were often very elongate. The hind wings were similar to the fore wings in shape and venation, they were a little broader than the fore wings, but did not possess an enlarged anal area.[7] The fundamental pattern of the venation seems to have been much the same in all families, so far as known. At first glance this pattern seems very simple and generalized, with MA, MP, CuA, and CuP present. However, a more detailed study of the veins, especially with reference to their convexity or concavity, reveals a most perplexing condition, and, in my opinion, a highly specialized one. The identity of the subcosta, radius, and radial sector is obvious. Sc is long, extending at least to mid-wing and often to the apex; R1 is unbranched and terminates about at the apex; Rs usually originates somewhat proximally of the mid-wing and gives rise to a variable number of branches, from two to many. The homology of the next three longitudinal veins is more difficult to determine. The convexity or concavity of all veins, except the

[5] The reasons for this conviction will be discussed in my revisional study of the insects of the Commentry shales, now in preparation.

[6] Martynov has published a good restoration of one of the species from the Permian of Russia, though not all the details shown in his figure are actually known (1938b, p. 126, fig. 63).

[7] Zeuner has stated (1938, p. 69) that the hind wings of the Caloneuridae possessed an anal fan. I do not know any basis for this assertion. None of the specimens which I have seen, including those from Commentry, show this anal fan and so far as I am aware no other mention of it occurs in the literature on the Caloneurodea.

anals, is very strong; this is true of Sc and Rs, which are concave, and of R1, which is convex. Below Rs is a forked vein (labeled 1 in figure 8) which arises directly from the vein below it; this vein (1) and both of its branches are strongly concave, like Rs The vein from which it arises (labeled 2 in figure 8) is very strongly convex, paralleling this vein and situated just below it is a concave vein (3 in figure 8) In his 1906 treatise on fossil insects Handlirsch figured the wing of the Carboniferous *Caloneura* and identified vein 1 (figure 8) as the media, and veins 2 and 3 as branches of Cu This is the obvious interpretation of the veins, made without regard to their convexity or concavity Lameere, in 1917, identified vein 1 of *Caloneura* as the media, vein 2 as CuA (+) and vein 3 as CuP (−) This interpretation agrees with the convexity and concavity of assume that these particular veins have changed through evolutionary processes from a concave position to a convex one or vice versa I do not believe such changes have ever been demonstrated in the insects (except perhaps in the case of elytra, where the thickening of the wing introduces another factor), and until that has been done, I consider Martynov's interpretation untenable The following identification of the veins is used here· vein 1 is MP (−), MA having been lost; vein 2 is CuA (+), being coalesced proximally with MA, vein 3 is CuP (−) I must admit, however, that one peculiarity of the venation of the Caloneurodea leads me to have a suspicion of doubt about even this interpretation The vein here designated as CuP, although close to CuA for most of its length, diverges away from it proximally and coalesces with the base of

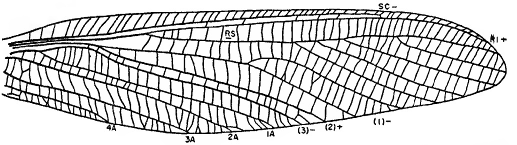

FIGURE 8. *Caloneura dawsoni* Brongn (Carboniferous of Commentry, France) Original drawing, based on types in the Muséum d'Histoire Naturelle, Paris Sc, subcosta; R1, radius, Rs, radial sector, MA, anterior media, MP, posterior media, CuA, anterior cubitus; CuP, posterior cubitus; 1A, 2A, etc , anal veins; +, convex veins, −, concave veins For explanation of (1), (2), (3), see text

the branches of Cu Martynov (1928) in his description of *Euthygramma*, and Tillyard (1937) in his account of *Permobiella* (which he placed in the Neuroptera) interpreted the venation of their respective genera in like manner In 1938, however, Martynov, after a survey of the Order Caloneurodea, proposed a new interpretation, designating vein 1 as MA, vein 2 as MP, vein 3 as CuA, and the concave vein below the last as CuP [8] As Martynov has noted, according to this interpretation, MA is concave, MP is convex, CuA concave, and CuP convex These are exactly the reverse positions of the homologous veins in other insects Such an interpretation can therefore be valid only if we

[8] Unfortunately Martynov based this interpretation on the structure of the genus *Euthygramma*, which differs radically from all other Caloneurodea in having vein 2 remote from vein 3, and in having the latter very close to the concave vein below it See Martynov, 1938a, figure 1a, p 71.

the vein below (here identified as 1A), which shows neither convexity nor concavity This basal coalescence is apparently a characteristic of the order, for it occurs in all genera, Carboniferous as well as Permian, which have been found The difficulty of the present interpretation is that CuA and CuP do not originate from a common stem, instead, CuP arises from the base of 1A Such a common origin of 1A and CuP does occur, of course, among living insects, but its presence in the Caloneurodea adds another specialization to a wing which at first glance seems to be generalized

The anal veins of the Caloneurodea vary from five in the Carboniferous species to two in some of the Permian members. One of the most striking features of the wings of these insects is the convexity of the numerous cross-veins In all known species the cross-veins are very heavy and are often stronger than the longitudinal veins. This peculiarity and the proximity of CuA and CuP (or CuP and 1A in

Euthygramma) are the two chief characteristics by which the order may be recognized.

The classification of the species of Caloneurodea into families is at present very uncertain Since we know but few species within the order, any classification is likely to be more convenient than natural Hence, whatever family classification is now adopted will undoubtedly need to be modified as additional species become known Inasmuch as the new genera from the Elmo limestone do not fit satisfactorily into families already established, I have been compelled to erect three new families for them. A survey of all described genera of the order, both Carboniferous and Permian, reveals two striking facts: 1) all genera are very similar in general pattern of the venation, and 2) all show intermediate conditions of their generic characteristics The pronounced upward arching of MA1 + 2 in the new genus *Apsidoneura* is illustrative of the latter. This arching is present to a slight extent in several of the Permian genera and especially in the Carboniferous *Homaloneura*. Another illustration is furnished by the branches of Rs These range from six or seven in the Caloneuridae to none in *Euthygramma;* but the number of branches varies specifically to such an extent as to render it useless for generic diagnosis. There are many other venational characteristics which show the same tendency So far I have found it virtually impossible to erect the framework of a satisfactory classification of these peculiar insects

The affinities of the Caloneurodea are not very clear. They are undoubtedly a part of the Orthopteroid complex and may be, as Martynov believed, an offshoot of the early Protorthoptera Zeuner has suggested (1939) that the Caloneuridae might be related to the ancestors of the Acridioidea, and also has stated that the primitive acridioid family Locustopsidae could easily be derived from the Caloneuridae I find it difficult to conceive of such a relationship on the basis of our present knowledge. Whether or not the Caloneurodea require permanent separation from the Protorthoptera as a distinct order can only be decided after many more species and anatomical details are known than now.

Paleuthygrammidae, new family

Fore wing: long and slender; costal area of moderate width, Sc long, terminating not far from the apex of wing; *Rs* arising near the middle of the wing, with two or rarely three branches, MP arising well before and forking beyond the origin of Rs; CuA and CuP straight and very close together, terminating in the distal fourth or fifth of the wing; 3 anal veins; 1A and 2A close together proximally, diverging distally, 3A sigmoidally curved, terminating at about mid-wing; cross-veins numerous, usually straight, sometimes sigmoidal. The fore wing (and perhaps the hind also) has a peculiar, granular texture. This is indicated in only one, splendidly preserved wing (no. 15572ab), but the absence of the granular structure in other fossils is almost certainly a matter of poorer preservation of the insects The granulation is apparently caused by numerous minute dark spots, resembling the bases of microtrichia No macrotrichia or microtrichia are visible on any of the wings.

Hind wing only a little shorter than the fore wing; the costal space is somewhat narrower than that of the fore wing, and hind margin is more curved proximally.

The body structure is very little known. The head was of moderate size, the antennae and legs elongate, as in other Caloneurodea.

This family is erected for two new genera and also for several genera which Martynov placed in the Euthygrammidae The genus *Euthygramma*, on which the latter family was based (Martynov, 1928), is so different from the other genera included there that I believe it requires a separate family. These differences are chiefly the unbranched Rs and the proximity of CuP and 1A, instead of CuA and CuP, as in other genera

The family Paleuthygrammidae, which is known from the Permian of Russia and Kansas, includes the following genera: *Paleuthygramma* Mart., *Vilviopsis* Mart, *Vilvia* Zal, *Pseudogramma*, n. gen., and *Apsidoneura*, n gen. *Vilvia* is readily distinguished by the density of the cross-veins *Paleuthygramma* may be defined at present as including those species with a forked Rs *Vilviopsis* has a radial sector with three branches, but I suspect that additional specimens of *Paleuthygramma* will show that generic separation because of the difference of one branch of Rs will not hold The new genus **Pseudogramma** is here erected by me for *aberrans* Martynov, which was placed by its author in *Euthygramma* Martynov considered it probable that MP in this species was coalesced with Rs. In view of the structure in additional Caloneuridae, however, I believe that such a condition is most improbable and that MP is really unbranched, as in one of the Kansas species of Caloneurodea. This, of course, implies that the straight and nearly contiguous veins in the wing are CuA and CuP. However, in either case, i. e., whether MP is a simple vein or is coalesced with Rs, a distinct genus appears necessary for this species.

Two genera of this family, *Paleuthygramma* and *Apsidoneura*, n. gen., occur in the Elmo limestone.

Genus *Paleuthygramma* Mart

Paleuthygramma Martynov, 1930, Ann. Soc. Pal. de Russie, 8: 42; 1938, Trav de l'Inst. Paléont, 7: 126.

Fore wing: Sc terminating at about the level of the fork of Rs, usually a little proximad to it, Rs arising at mid-wing, or slightly before it and forked dichotomously near the apex of the wing; MP deeply forked, almost to half its length, 2A and 3A sinuously curved. The cross-veins are numerous, as characteristic of the family, most of them are straight, but those in the distal part of the wing tend to be sigmoidal. Hind wing similar to the fore wing, but with a narrower and straighter costal margin; apex slightly more rounded than that of fore wing; 3A more curved than in fore wing.

This genus was established by Martynov for the single species *tenuicornis* Mart, from the Permian of Russia The unique type consisted of a whole specimen, which showed the general body structure and most of the venation of one wing. A closely related species is represented in the Yale and Harvard collections from the Elmo limestone. In fact, its venation is so close to that of *tenuicornis* that I have found it impossible to separate the two species generically, in spite of the great difference in their geographic range.

Paleuthygramma acuta, n sp.

Figure 9

Fore wing. length (holotype), 18 mm.; width, 3 mm.; costal margin slightly narrowed at very base; Sc terminating before the level of the forking of Rs; Rs with a conspicuous though shallow fork; sometimes the alignment of cross-veins within the latter fork gives the impression of a weak intercalated vein between its branched, point of separation of MP from Cu variable, but always well proximal to the origin of Rs, anterior branch of MP slightly curved in its distal half, 1A close to 2A proximally; 2A slightly curved sigmoidally; 3A arched near the base of the wing Hind wing· length (holotype), 17 mm, width, 4 mm., similar to the fore wing, except for the differences noted under the genus.

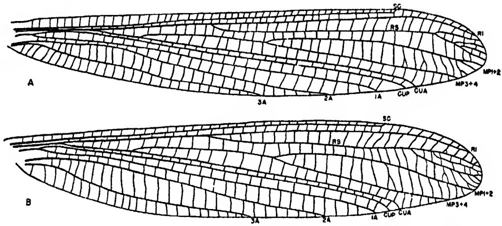

FIGURE 9. *Paleuthygramma acuta*, n sp. A, fore wing; drawing based chiefly on holotype and specimen no. 4563, Mus. Comp. Zool. B, hind wing, drawing based chiefly on holotype and specimen no 4554, Mus Comp. Zool. Lettering as in figure 8.

Very little is known of the body structure of this insect The abdomen, preserved in three specimens (Peabody Museum, 15655, M. C. Z. 4587, 4547) is 9 mm long and 2.5 mm. wide One specimen (M. C Z. 4547) shows several terminal abdominal appendages. Two of these (3 mm. long) are segmented and are probably cerci, the others, included between the cerci, are incomplete and I have not been able to determine their precise form. The prothorax (M. C Z 4587) is 2 mm. long and 2 mm. wide. The legs were obviously long and slender; the middle femur is 5 mm. long and the tibia is at least 4 mm. long, since that much of a tibia is preserved without the distal end being evident. One

hind tibia is preserved (M. C Z 4545); this is 9 mm. long The tarsal segmentation is unfortunately not known. The body structure of *acuta*, as far as known, was apparently much like that shown in Martynov's restoration of *Paleuthygramma tenuicornis* (1938, fig 63), except that the legs of *acuta* were probably longer

Holotype Museum of Comparative Zoology, No 4587ab, collected in the lower layer of the limestone at Elmo, 1935 (F M Carpenter) This consists of a partially complete insect, three wings extend along the abdomen, and one fore wing, preserved only to about the middle, lies at right angles to the body. This specimen therefore shows part of a fore wing and at least one complete hind wing, though the proximal part of the latter is obscured by the abdomen

Paratypes as follows Two in the Peabody Museum, Yale University, collected in the Elmo beds by C O Dunbar No 15572ab, a fore wing, very well preserved, but with the posterior part, below 1A, broken away, this specimen shows clearly the texture of the wing No 15571, a nearly complete fore wing, with apex missing

Nine in the Museum of Comparative Zoology, all collected at Elmo, 1927–1935 (F M Carpenter) No 4563ab, basal third of fore wings, excellent preservation (upper layer of limestone), No 4554, a nearly complete hind wing, apex missing (lower layer), No 4566, basal half of fore wing (upper layer), No 4558ab, basal third of fore wing, excellent preservation (upper layer), No 4547ab, parts of wings and body, especially the abdomen (lower layer), No 4560ab, distal third of wing, excellent preservation (lower layer), No 4556, nearly complete fore wing (lower layer), No 4558ab, nearly complete fore wing (upper layer)

In addition to these twelve type specimens, there are four other specimens in the Yale collection (Nos 15661, 15655b, 15657ab, 15656a) and twenty in the Museum of Comparative Zoology These make a total of thirty-five specimens in both collections

Since none of these shows either a fore or hind wing entirely complete, the drawings in figure 9 have been based on several specimens A comparison of figure 9 with that of *Paleuthygramma tenuicornis* Mart., the genotype, reveals the close similarity of the species. Probably a greater difference exists in the anal area, which is not preserved in the genotype, but I do not believe that this will be enough to require generic separation of the two species.

The correlation of the fore and hind wings of this insect is made possible chiefly by the holotype, which includes parts of all four wings. The differences are indeed slight, as indicated above, and are mainly confined to wing shape. This difference in shape between the fore and hind wings is almost certainly a generic characteristic.

The individual fossils show slight variation in venation The place of origin of MP is subject to slight variation as is also the depth of the forks of Rs and MP, but the individual differences are not comparable in extent to those in the Protoperlaria and most other groups of Permian insects (see Carpenter, 1935).

Apsidoneura, new genus

Wings subpetiolate and slender, though not so elongate as in *Paleuthygramma*, Sc terminating almost at very apex of wing, Rs arising somewhat nearer the base than the apex, with 2–3 branches, MP originating at point of separation of Cu from R and M, and forking well beyond mid-wing; anterior branch of MP strongly arched towards Rs, CuA and CuP straight and very close together, CuP and 1A coalesced basally, 3 anal veins present, 1A remote from CuP, 3A somewhat shorter than in *Pseudogramma* and *Paleuthygramma*

This genus is known only from two isolated wings, both are probably fore wings

Apsidoneura flexa, n sp

Figure 10, plate 1, fig 2

Length of wing (holotype), 30 mm , maximum width, 6 5 mm Costal margin straight, apex rounded, posterior margin convex, proximal third of wing more slender than rest; costal space much broadened in proximal half, but narrowed distally, R1 terminating at apex of wing; Rs curved anteriorly towards R1 opposite the upward curve in anterior branch of MP; MP straight from its origin to its fork, anterior branch of MP arching abruptly towards Rs for a short distance, them curving posteriorly, CuA and CuP are weak and twigged at their terminations, 1A terminating about at level of fork of MP, 2A terminating just beyond level of origin of Rs, 3A well developed but close to wing margin Cross-veins numerous, convex, the longer ones sigmoidally curved In the region of the branches of Rs some cross-veins have aligned to form short intercalated veins

Holotype No 4572ab, Museum of Comparative Zoology, collected in the upper layer of the Elmo limestone, 1932 (F M Carpenter). This is a splendidly preserved specimen.

Paratype· No. 4551, Museum of Comparative Zoology, collected in the lower layer of limestone at

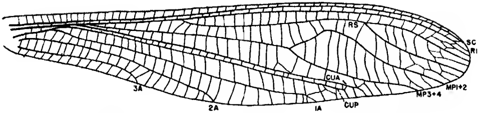

FIGURE 10 *Apsidoneura flexa*, n sp Drawing of holotype Lettering as in figure 8

Elmo (F. M. Carpenter) This is an incomplete wing, lacking that part of the wing which is proximal to the separation of MP from R + M. The wing is 23 mm long as preserved and 6 5 mm wide The venation is identical with that of the holotype, except that Rs is 3-branched, R2 + 3 forking near the apex

This species unquestionably requires generic separation from the other members of the family It is distinctive in possessing the long Sc, arched MP1 + 2 and the relatively short 3A The form of MP is most peculiar, but it is interesting to note that a tendency for curvature of this vein occurs in *Pseudogramma* An even more pronounced approach to the condition of MP in *Apsidoneura* is found in the Carboniferous *Homaloneura similis* Meunier, which resembles *flexa* in several other respects, also

Pleisiogrammidae, new family

Wings moderately slender, costal area of moderate width, Sc long, extending beyond mid-wing, Rs arising well before mid-wing, with 3 or 4 branches, MP arising before origin of Rs, not strongly arched towards Rs; CuA and CuP straight and close together, terminating just distad to mid-wing, much shorter than in Paleuthygrammidae, CuP and 1A coalesced basally, only two anal veins well developed, 3A reduced to a small vestige at base of wing, cross-veins numerous, but less so than in Paleuthygrammidae.

This family is established for two new species, both represented by isolated wings Their venation is so different from that of other Caloneurodea that I have been unable to allocate them to any described family They apparently represent a specialized branch of the order, characterized by almost complete loss of the third anal vein. I have tentatively placed both species in the single genus *Pleisiogramma*, but it may eventually be necessary to separate them at least generically However, since we know nothing of the differences between their fore and hind wings, I have considered it advisable to group them into one genus until this important aspect of their structure is known

Pleisiogramma, new genus

Wings subpetiolate, Sc extending at least as far as the fork of Rs, MP either deeply forked or simple, end of CuA and CuP weak distally and twigged, 1A close to 2A proximally, more remote distally, 2A ending at about mid-wing or just before it

Genotype *Pleisiogramma medialis*, n sp.

Pleisiogramma medialis, n. sp.

Figure 11

Length of wing, 17 mm , width, 4 5 mm , costal margin straight or nearly so, with a slight curve basally, apex rounded, posterior margin strongly curved, Sc extending almost to very apex of wing; Rs arising about one-fourth of wing length from base, and forking into R2 + 3 and R4 + 5 just beyond mid-wing, R2 + 3 forked soon after its origin, and R2 also deeply forked, R3 and R4 + 5 are slightly curved distally towards R2, MP arising slightly before the origin of Rs, unbranched; 2A

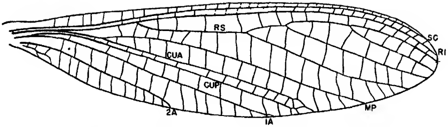

FIGURE 11 *Pleisiogramma medialis*, n sp Drawing of holotype Lettering as in figure 8

terminating well before mid-wing, 3A very short and close to posterior margin; cross-veins numerous, mostly sigmoidal.

Holotype· No. 4540ab, Museum of Comparative Zoology, in the upper layer of the Elmo limestone (F. M. Carpenter) The specimen consists of a very well preserved wing, which might be either a fore or hind wing.

This species differs from all the other Caloneurodea, except *Pseudogramma aberrans* Mart, in having an unbranched MA. The possibility that MA actually is forked and that its anterior branch is coalesced proximally with Rs, does not seem to me at all likely If this were the case, a portion of MP leading to Rs should be visible Since MP and Rs are strongly concave, this piece of MP would of only a small strip along the apical and posterior margin The cross-veins are clearly preserved in the proximal part of the wing, but are obscure distally.

This species resembles the foregoing in the wing shape and the reduction of the third anal vein. It differs from *medialis*, however, in a number of respects, such as the shorter Sc and forked media; these differences and others may eventually require the erection of a distinct genus for *reducta*. Until a complete specimen of either species (showing both fore and hind wings) has been found, and proven the contrary, the possibility remains that *medialis* and *reducta* are based upon fore and hind wings of one species However, in view of the nature of the differences between them, the chances of this seem very remote

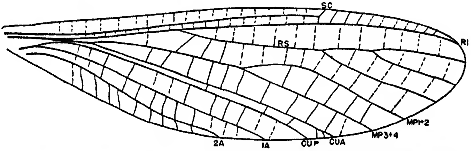

FIGURE 12. *Pleisiogramma reducta*, n sp Drawing of holotype. Lettering as in figure 8

course also be concave, but all of the cross-veins between MP and Rs are strongly convex.

Pleisiogramma reducta, n sp.

Figure 12

Length of wing, 15 mm, width, 4 mm The wing shape is essentially like that of *medialis*. Costal area a little broader than that of the latter; Sc terminating at about a third the wing-length from the base, directly above the first fork of Rs, Rs arising nearer the middle of the wing than in *medialis* and giving rise to 3 branches, R4 + 5 and R2 and R3; MP arising much nearer the base than the point of origin of Rs and forked at about mid-wing, its posterior branch continues the line formed by the stem of MP, and its anterior branch is directed gradually anteriorly; CuP and 1A close together at base, remote distally; 2A is somewhat longer than in *medialis;* 3A is not preserved, but if present it is obviously very short.

Holotype: No. 4553ab, Museum of Comparative Zoology, collected in the lower layer of the Elmo limestone, 1927 (F. M. Carpenter). This specimen consists of a fairly well preserved wing, which lacks

Anomalogrammidae, new family

Wings slender, but not subpetiolate; costal area of moderate width; Sc relatively short, terminating at about mid-wing, space between R1 and costal margin, beyond end of Sc, very broad; Rs arising well before mid-wing, forked, MP arising nearly at point of separation of Cu from R + M, deeply forked; CuA not so close to CuP as in Paleuthygrammidae, CuP twigged distally; CuP and 1A coalesced basally; only two anal veins are present in the fossil on which the family is based, but a third anal vein might have been present in the original wing, since this part of the wing is poorly preserved Cross-veins convex but relatively few in number

This family is erected for a species having a very peculiar venation. Sc is shorter than in other members of the order, R1 diverges away from the costal margin beyond the end of Sc, and the cross-veins are not at all numerous (i. e., for a Caloneurodean). Because of these characteristics and several others not occurring elsewhere in the Caloneurodea, I have considered a distinct family necessary for this insect. The family is apparently related to Paleuthygram-

midae, but includes more highly specialized species with a greater reduction of the venation.

Anomalogramma, new genus

Wings with the proximal half much more slender than the distal half; Sc terminating at mid-wing, MP forked just below the end of Sc, its anterior branch arched slightly towards Rs at first, then curved away; CuA close to CuP proximally, but diverging from it distally; CuA and CuP weak and twigged distally.

Genotype. *Anomalogramma parva*, n sp.

Anomalogramma parva, n sp.

Figure 13

Wing. length, 9 mm., width, 2 mm , costal margin straight, apex rounded, posterior margin only slightly curved; Sc close to R proximally but diverging abruptly towards costal margin soon after the origin of Rs, Rs forked to about a third of its length, Rs arched towards MP just beyond mid-wing, then curved upwards towards R just before forking, CuA slightly zigzagged distally, CuP more so, extending apically towards CuA along hind margin of wing; 1A nearly straight The longer cross-veins are sigmoidally curved.

Holotype: No 4561, Museum of Comparative Zoology, collected in upper layer of Elmo limestone, 1935 (F. M. Carpenter). This specimen consists of a nearly complete wing, lacking only a very small piece near the apex The preservation is good for such a small wing, though many of the cross-veins are not discernible. Whether the specimen is a fore or hind wing cannot be determined at present

This insect is the smallest member of the Caloneurodea so far known. The venation as a whole is fundamentally like that of the Paleuthygrammidae but differs in the structure of the individual veins, as indicated under the genus.

Family PERMOBIELLIDAE

Wings moderately slender, not subpetiolate; costal area of moderate width, Sc terminating not far from mid-wing. R1 longer than in Paleuthygrammidae, extending to the very apex of the wing; Rs arising before mid-wing, with 3 branches; MP arising at point of separation of Cu from R, deeply forked; CuA and CuP close together proximally, but diverging distally, 1A remote from CuP; at least 2 anal veins present

This family was placed by Tillyard in the order Neuroptera He apparently overlooked the very close similarity between its venation and that of the Caloneuridae or Martynov's family Euthygrammidae, for neither of these is mentioned in his discussion of the fossil. Martynov has already shown that the true position of the Permobiellidae is with the Caloneurodea (1938a, 1938b) The Permobiellid venation differs from that of all other families in the order by the pronounced divergence of CuA and CuP distally as well as by the extraordinary convexity of the cross-veins, and the length of R1.

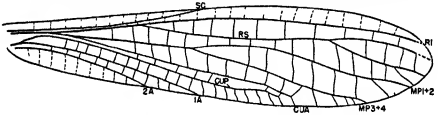

FIGURE 13 *Anomalogramma parva*, n sp Drawing of holotype Lettering as in figure 8

Genus *Permobiella* Till

Permobiella Till , 1937, Amer Journ Sci , **33: 101**; Martynov, 1938, **7**: 80

Wings with the proximal half much narrower than the distal half, Sc terminating very slightly beyond mid-wing, MP forked to about mid-wing, its anterior branch very slightly arched towards Rs; CuA slightly zigzagged distally and twigged, CuP parallel to CuA proximally, but curved away distally. Cross-veins very strongly convex, more so than in any other genus of Caloneurodea.

Genotype *Permobiella perspicua* Till.

Permobiella perspicua Till.

Figure 14

Permobiella perspicua Till , 1937, Amer. Journ. Sci., **33: 102**

Wing· length of wing fragment (holotype), 11 mm , width, 3 6 mm , the basal part of the wing, proximal to the origin of MP, is missing, the complete wing was probably about 14 mm. long. Costal margin slightly arched, apex probably pointed (not rounded as drawn by Tillyard); posterior border

nearly straight, R4 + 5 is about one-half as long as the entire Rs; R2 and R3 are nearly as long as R4 + 5; between the branches of Rs, the cross-veins form short intercalated veins; nearly all cross-veins in the wing are sigmoidally curved and are dark brown.

Holotype: No 15593, Peabody Museum. This consists of a nearly complete wing, lacking the proximal fifth.

In the Museum of Comparative Zoology there is one specimen (no 4552ab, lower layer of the Elmo limestone); this consists of the distal half of a wing.

Tillyard's figure of *perspicua* is incorrect in several respects The apex of the wing is partially obscured by a plant fragment in the holotype, and the part of the apex that is preserved is obviously distorted

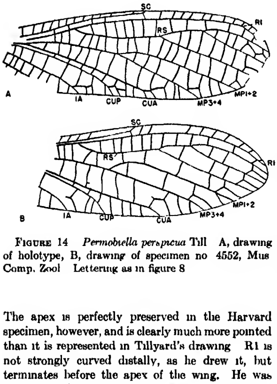

FIGURE 14 *Permobiella perspicua* Till A, drawing of holotype, B, drawing of specimen no 4552, Mus Comp. Zool Lettering as in figure 8

The apex is perfectly preserved in the Harvard specimen, however, and is clearly much more pointed than it is represented in Tillyard's drawing R1 is not strongly curved distally, as he drew it, but terminates before the apex of the wing. He was also under the erroneous impression that the holotype was practically complete and he indicated the base of the wing just beyond the limits of the fossil. In view of the structure of other Caloneurodean wings, however, I believe this wing was much longer than he supposed.

Tillyard noted, and also indicated by the specific name *perspicua*, that the cross-veins of this wing were remarkably convex Their dark brown color adds to their prominence and makes them far more conspicuous than the longitudinal veins [9] There is a noticeable difference in the number and arrangement of the cross-veins between the holotype of *perspicua* and the specimen in the Harvard collection. This discrepancy is almost certainly due to individual variation, rather than to specific difference. The occurrence of several incomplete cross-veins in the Harvard specimens is strong support of this conclusion

Order PROTORTHOPTERA

This order was established by Handlirsch in 1906 for a series of Carboniferous and Permian insects, presumably transitional between the Paleodictyoptera and the Orthoptera (s. l) Since its erection, the order has become a vague assemblage of all Paleozoic insects which show traces of Orthopteroid characteristics The taxonomic confusion of these fossils has been increased by the gradual diminution of the distinctions between the Protorthoptera and Protoblattoidea, another Paleozoic order erected by Handlirsch for species supposedly intermediate between the Blattaria and Paleodictyoptera In recent years, an extensive series of Carboniferous and especially Permian species has been described which cannot be placed definitely in either of these orders Many attempts have been made to divide the order into several suborders (e g Handlirsch, 1937), but there have always remained a great many families and genera which failed to fit into the proposed divisions Several of the suborders thus formed have subsequently been completely removed from the Protorthoptera and set up as distinct orders (e g Caloneurodea), but these moves have had little effect on the extreme heterogeneity of the remaining Protorthoptera Martynov has attempted (1938b) to obtain some homogeneity by restricting the order so as to include only the Paleozoic saltatorial Orthopteroids; the non-saltatorial forms he places in a distinct order, Paraplecoptera Even if such a classification is assumed to have a phylogenetic basis, which seems dubious, it is obvi-

[9] This is indicated clearly in the photograph of the Harvard specimen of *P perspicua* published in the Annals of the Carnegie Museum, 1934, vol 22, pl 24, fig 2 It should be noted that as a result of an error which escaped my attention in the proof, the caption under this figure is incorrect. It should read, "A Caloneurid from the Lower Permian of Kansas, No. 4552, Museum of Comparative Zoology Note the thickness and convexity of the cross-veins. About x5" This photograph of *perspicua* was included for comparison with *Caloneurella carbonaria*, described in the text

ously impractical, for the leg structure is unknown in more than four-fifths of the species which have been placed in the Protorthoptera.

In my opinion, most of the difficulties encountered in the taxonomy of the Protorthoptera have resulted from two factors In the first place, many of the species, genera and families have been founded on small wing fragments, too incomplete to permit determination of their affinities Such fragmentary material will have to be ignored in the formation of a taxonomic system within the order In the second place, many of the species have been so incompletely and inaccurately described that their true affinities have not been apparent The majority of the known Protorthoptera are from the Carboniferous and have been described by Scudder, Brongniart, Meunier and Handlirsch. The figures and descriptions of Scudder and Brongniart, though accurate and complete enough for the need of their times, do not include many details (as convexity and concavity of the veins) which are now essential, those of Meunier, as is well known, are totally unreliable, and those of Handlirsch, though better than Meunier's, are usually incomplete and very erratic [10] The deplorable state of the literature on the Protorthoptera convinced me several years ago that a "revision" of the Carboniferous Protorthoptera, based on published figures and descriptions, would in no way ameliorate the taxonomy of these insects For this reason I have spent a large part of the past three years in a study of the type specimens of this group of fossils, both European and North American This task has now been completed and the drawings and descriptions are being assembled for publication A discussion of the classification of the Protorthoptera will be included there In the present paper and in the subsequent part in this series, I shall use the term Protorthoptera in a broad sense, and shall not attempt to anticipate the account of the Carboniferous species

Family Probnisidae

The family Probnisidae was established by Sellards (1909) in the Protorthoptera for a series of insects from the Elmo limestone having coriaceous fore wings and a Protorthopterous venation. Up to the present time the family has not been found in any other formation, so that our knowledge of it is restricted to the data provided by the Kansan fossils. Sellards described four genera and eight species in this family, but Tillyard, after a study of nearly a hundred specimens in the Yale collection, was able to demonstrate that all of these genera and species really represented a single variable species, *Probnis speciosa* Sellards [11] From my study of the Harvard collection of Probnisids, numbering about 250 specimens, I am convinced that his synonymy is absolutely correct and also that the family Probnisidae is now known to us by only this species.

The representatives of this insect in Sellards' collection consisted of isolated fore and hind wings, but a number of the specimens which were in the Yale collection and which were described by Tillyard show parts of the body In the Harvard collection there are many additional specimens with body structures preserved, so that we are now able to obtain an unusually good concept of the general structure of this insect Sellards placed the Probnisidae in the Order Protorthoptera, but Tillyard concluded from his study of the Yale fossils that they were aquatic in their nymphal stages and therefore belonged to the Order Protoperlaria. I do not agree with this conclusion I believe that the nymphs of *Probnis* were terrestrial and that the genus was closely related to the Gerandae, Ischnoneuridae and other Orthopteroids which have been placed in the Protorthoptera The reasons for this view, as well as corrections to Tillyard's comments on my concept of the Protoperlaria, will follow the detailed description of *Probnis speciosa*.

The Probnisidae may now be characterized as follows Insects of moderate size Head rather small, eyes prominent and protruding laterally; antennae shorter than the thorax, robust. Thorax large and broad; prothorax short, with a small notum and a pair of moderate-sized but distinct lateral lobes, slightly overlapping the mesothorax; legs heteronomous, the prothoracic pair much shorter than the hind or middle pair, the tibia of all legs forming distally a series of conspicuous finger-like projections, these being largest on the fore legs, tarsi apparently 3-segmented Abdomen long and robust, cerci short Fore wing slightly granular in appearance, coriaceous, but not elytriform; Sc terminating on the costa before the apex of wing; R1 unbranched, extending to apex; Rs arising in the proximal half of the wing, unbranched; MA and MP separating at about the level of the origin of Rs, both of these veins very variable in respect to branching; CuA and CuP separating close to the base of the wing; CuA dividing shortly after its origin into two main branches, CuA1 and CuA2;

[10] For an example of the confusion resulting from the work of Handlirsch and Meunier, see my note on the Commentry Caloneuridae (Carpenter, 1934, p. 325–326).

[11] With the possible exception of one unrecognizable species, *Lecopterum delicosum* Sell.

CuA1 gives rise to a variable number of arched branches along the posterior margin of the wing, CuA2 usually simple; CuP unbranched, straight; 1A straight and usually simple. Hind wing. membraneous, but with a definite trace of the wrinkles which are better developed in the fore wing, costal space much narrower than in the fore wing; Sc and R1 essentially as in the fore wing, Rs arising almost at the very base of the wing, unbranched, MA and MP simple (usually) or forked; CuA separating from CuP at the very base of the wing and giving rise to several arched branches similar to those of the fore wing, except that they are usually longer, CuP straight and unbranched, terminating at the re-entrant angle of posterior margin, anal fan well developed, with at least six main veins, all of these arising from a single proximal stem

Tillyard recognized two genera in the family in addition to *Probnis* itself *Lecopterum* Sellards and *Telactinopteryx* Tillyard The former genus was based upon a single fore wing (*delicosum* Sell), which was inadequately described by Sellards, without a figure The type specimen was missing from the Sellards' collection when I studied his types in 1927 Since the identification of further specimens of *delicosum* is almost hopeless, as pointed out by Tillyard, I propose to regard the name *Lecopterum delicosum* as a *nomen nudum* *Telactinopteryx* was based upon a single species (*striatipennis* Till) and placed in a separate subfamily In my opinion this species does not belong to the Probnisidae Its eyes are very small, the prothoracic lobes almost absent, the tibiae are unmodified, the cerci multisegmented, the wings lack the granulation described above in *Probnis*, and their venation is distinctly different from that of the latter genus I therefore establish a distinct family, **Telactinopterygidae**, for this genus *Probnis* consequently remains the only known genus of the family Probnisidae

Genus *Probnis* Sellards

Probnis Sellards, 1909, Amer Journ Sci, **27**: 159; Tillyard 1937, ibid, **33**: 417
Espira Sellards, 1909, ibid, **27**: 160
Stoichus Sellards, 1909, ibid, 160
Stinus Sellards, 1909, ibid, 161

Since only one species of this genus is known, and that one species has a very variable venation, it is impossible to do more than to suggest generic characteristics. Tillyard has given a very detailed account of the venation under the genus, but nearly all of his statements are clearly specific rather than generic in nature; Tillyard himself apparently realized this, since he completely omitted description of the venation under the species. In all probability such general body characteristics as the relative size of the prothoracic lobes and the relative length of legs and cerci are of generic rank; and very likely also such general venational characteristics as the approximate position of the origin of Rs and MA are in the same category I regard the peculiar coriaceous texture of the wings as a family trait, rather than a generic one, as it was treated by Tillyard.

Genotype. *Probnis speciosa* Sellards

Probnis speciosa Sellards

Figures 15, 16

Probnis speciosa Sellards, 1909, Amer Journ Sci, **27**: 159, Tillyard, 1937, ibid, **33**: 417
Probnis coriacea Sellards, 1909, ibid 160
Espira obscura Sellards, 1909, ibid · 160
Stoichus elegans Sellards, 1909, ibid. 160
Stoichus arcuatus Sellards, 1909, ibid 161
Stoichus minor Sellards, 1909, ibid · 161
Stoichus tenuis Sellards, 1909, ibid 161
Stinus brevi-cubitalis Sellards, 1909, ibid · 161
Probnis sellardsi Handlirsch, 1919, Denkschr der Akad Wiss Wien, **96**: 33

Fore wing length, 9–14 mm.; width, 3–4 mm Costal space narrow, almost always with a few veinlets, sometimes with many, Sc ending at about mid-wing, its actual point of termination usually obscure because of the vein's faintness, Sc is nearly straight in most specimens, but is distinctly curved in others, R usually joined to Sc or to the costal margin by several veinlets, which are oblique and often forked beyond the end of Sc, R1 and Rs unbranched, MA and MP consistently diverging at about the level of the origin of Rs, both MA and MP are unbranched in about 50% of the specimens, but either one or both may be forked, though the forks do not extend at most to more than a third of the wing length from the apex, MP is usually weak proximally; CuA is the strongest vein in the wing and it is also the most variable; CuA2 usually arises quite near the base of the wing. The marginal, arched branches of CuA1 vary from four to nine, the distal branches being longer than the proximal ones, CuP is always weak and straight; the anal veins are highly variable, but at least 1A and 2A are usually recognizable

Hind wing shorter than fore wing, 7–12 mm. in length; Sc close to margin, ending beyond mid-wing, usually with a series of short distal veinlets, R1 with longer distal veinlets between it and the costal margin; Rs arising from R1 at a point nearer the base of the wing than in the fore wing; Rs always

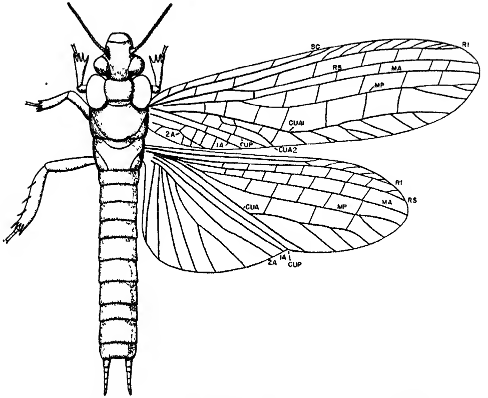

FIGURE 15 *Probnis speciosa* Sell. Restoration based on specimens in the Harvard collection Lettering as in figure 8

unbranched (not forked as drawn by Tillyard), MA and MP separating at a point nearer the base than in the fore wing; both may be either forked or simple; CuA with at least two distal branches, usually three, CuP straight, 1A very nearly straight, all the other anal veins may be an extension of 2A, since all arise from a single stem, the first vein below 1A is simple, the next forked and the others usually simple

It should be noted that Tillyard's description and drawing of the hind wing of *speciosa* are incorrect in several respects Rs arises much nearer the base of the wing than is shown in his figure and it does not fork; M is forked at about the level of the point where he has indicated the origin of Rs, instead of at mid-wing, CuA has two distal branches, between 1A and the vein which he labels 2A there is a simple straight vein. His drawing was based on an isolated hind wing in the Yale collection (15560), I have examined this specimen very carefully and compared it with hind wings in the Harvard collection The specimen figured by him is very poorly preserved, and the anal veins connot be distinguished satisfactorily. Under oblique illumination, however, the longitudinal veins in the wing proper are distinct and their structure is essentially like that shown in the accompanying figure (15) All other specimens of hind wings of this insect, whether isolated or attached to fore wings, have a similar venation.

Many specimens in the Harvard collection show various body structures The following description and measurements are based upon this material. The entire body, exclusive of the cerci, is about as long as the fore wing The head, which is apparently prognathous, is about as wide across the eyes as it is long (1 8 mm) The eyes are strongly protuberant, as they were depicted by Tillyard in his restoration of the head (1937, figure 7) The antennae, which are approximately 2 mm. long, are inserted just in front of the eyes and contain about 19 segments. The thorax is large and massive. The prothorax is small (9 mm. long) and the prothoracic lobes are of moderate size (1 mm long, 2 mm wide), and slightly overlap the mesothorax. The mesothorax is the largest thoracic segment (1.5 mm long, 2 3 mm. wide); the mesonotum is large and more or less cordate in form. The metathorax is smaller than the preceding segment (1.2

mm. long, 2 mm. wide) and has a smaller, subcordate notum. The three pairs of legs are markedly different in size The fore pair are 3 mm. long from the base of the femur, the middle pair, 3 8 mm long, and the hind pair 5 5 mm long The femur of all legs is moderately robust and of ordinary form, but the tibiae are most peculiarly modified. Each tibia terminates distally in a group of four finger-like projections [12] The fore tibiae, which are distinctly flattened and broadened distally, bear the longest projections The processes are obviously not moveable spines but appear to be rigid extensions of the tibia itself Several large, oblique spines are present along the sides of the hind tibiae, though I have not seen them on the other legs. The tarsus is attached to the tibia between two of the projections, apparently slightly on the dorsal surface of the tibia All tarsi are small (about 7 mm); those of the hind legs are 3-segmented, the first two segments being small, and the third about three times as long as the others [13] I have not been able to determine the nature of the segmentation of the middle and fore tarsi but it was almost certainly like that of the hind tarsi The abdomen is nearly homonomously segmented. There is absolutely no indication of lateral gill-vestiges, like those in the Lemmatophoridae (Protoperlaria). The cerci are stout and composed of 7 segments

Types: the holotype of *speciosa*, originally in the Sellards' collection, was lost in 1927. A neotype (no. 15518) was selected by Tillyard from the Yale material.

This insect is a common one in the Elmo limestone. Tillyard listed 99 specimens in the Yale collection; I find 37 in the Sellards' collection and about 250 in that of the Museum of Comparative Zoology These make a total of about 385 specimens. The accompanying restoration of this insect (figure 15) is based upon several specimens in the Harvard collection. All structures shown in the figure are preserved in at least one of the fossils, except the middle and fore tarsi, which have been drawn like the hind pair.

There are two features of this species which are especially noteworthy. One of these is the texture of the wing membrane and the other is the form of the tibiae As both Sellards and Tillyard stated, the fore wing has a distinctly coriaceous appearance. In all probability, however, the wing was not as thickened and heavy as that of even most cockroaches (such as *Blaberus*), for a great many of the specimens of *Probnis* have the fore wings twisted or folded, a condition which would hardly have taken place had the wing been very stiff. As Tillyard has mentioned, the granular appearance of the wing is produced by the presence of protuberant bases of

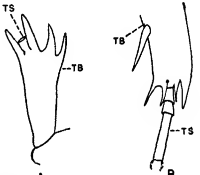

FIGURE 16 *Probnis speciosa* Sell. A, Drawing of fore tibia, based on specimen no 4615 and 4613, Mus Comp Zool B, drawing of hind tarsus and part of tibia, based on specimen no 4619, Mus Comp. Zool.

microtrichia, which are almost evenly distributed over the surface In only one specimen have I actually seen any of the microtrichia themselves; in this fossil they are very short and thin. Tillyard has stated his belief that the fore wings had soft, wavy hairs, forming a woolly covering. So far as I can determine, however, he did not actually see such hairs and I have failed to discern them in any specimens, including those in the Yale collection. Oddly enough, the subcosta of the fore wing was armed with a series of large spines, on the undersurface only. These spines, which are directed posteriorly extend almost the entire length of the vein. The significance of the wing texture and of the presence of the spines on the subcosta are not at all apparent; they may be in some way associated with the insect's habits or with the environment in which it occurred In connection with the modified tibiae,

[12] Tillyard's figure of the "fore leg" of *speciosa* (1937, fig 7) does not indicate these tibial projections. My examination of the specimen on which he based his drawing (no 15548, Peabody Museum) has shown that the leg figured was actually one of the middle pair and that the projections were broken away in the counterpart of the fossil, which was not collected. One fore leg of this specimen was preserved but it was covered by limestone matrix and was consequently not seen by Tillyard I have subsequently removed the matrix, so that the complete tibia, with the projections described above, is now visible.

[13] Tillyard has drawn the tarsus of *speciosa* (1937, fig. 7) with 5 segments, but this segmentation was pure assumption on his part, since, as he states, none of the Yale specimens showed the tarsal segmentation

it is noteworthy that the tarsi are distinctly suppressed. I have the distinct impression that the tarsi arose from the dorsal surface of the tibiae rather from the ventral side. The function of the tibial projections is very puzzling. They hardly seem of predatory significance, though this would be borne out by the prognathous head. The fore legs resemble those of the Gryllotalpids, and certainly suggest a fossorial function, but the structure of the other legs and of the rest of the insect does not support this indication. At present I am inclined to the belief that the tibiae might have played a part in climbing; this is consistent with the presence of the strong spines on the hind femora and of the modification of all tibiae

In synonymizing seven of Sellards species and three of his genera with *speciosa*, Tillyard was unquestionably correct, and I have considered it unnecessary to present further evidence for this from the material in the Harvard collection Handlirsch established one additional species for an incomplete hind wing which Sellards figured without attempting to determine its generic position This is of course another synonym.

Nothing is known about the immature stages of *Probnis*. Tillyard has stated that the abdomen of the adult shows a mottled pattern which assisted him to recognize as belonging to this species one of the commoner larval types in the Yale collection [14] His statement regarding the mottled pattern of the adult abdomen puzzles me greatly, for I have seen no indications of such a pattern in any specimens, including those in the Yale collection I do not believe there is any evidence whatever for associating the nymphs mentioned with the genus *Probnis*.

Relationship of the Probnisidae

After his study of the Yale specimens Tillyard came to the conclusion that the Probnisidae were aquatic in the nymphal stages and belonged to the Order Protoperlaria, and he presented a series of arguments to support this view. I do not believe that he has really proved his case, however It is my conviction that the Probnisidae had terrestrial nymphs and that they were Protorthopterous insects related to the Geraroidea Before discussing the evidence bearing on this question, however, we must first consider the differences between the Protoperlaria and Protorthoptera. In my account of the Protoperlaria of the Elmo limestone (Part 7 of this series), I showed that:

1 Prothoracic lobes like those of the Lemmatophoridae (the family on which the Order Protoperlaria was based) were likewise present in at least some of the Protorthoptera and could not therefore be used to distinguish these two orders, as had been proposed by Tillyard

2. The wing venation of the Lemmatophoridae was so similar to that of some of the Protorthoptera that this alone could not distinguish the two groups

3 The nymphs of the Lemmatophoridae were aquatic, possessing abdominal tracheal gills and swimming legs (This statement was based upon an extensive series of nymphs from the Elmo limestone in the Museum of Comparative Zoology)

4 The Lemmatophoridae lacked a fully developed external ovipositor.

5. Most, if not all, of the families of Protorthoptera in the Elmo limestone included species with a fully developed external ovipositor in the female.

My final conclusions were that the Order Protoperlaria should be restricted to include only species having aquatic nymphs, and that so far as known, the Lemmatophoridae was the only family that would fit into the order as so defined.

My views on the relationship between the Protoperlaria and Protorthoptera were stated as follows: the order Protoperlaria "stands in direct evolutionary line leading to the Perlaria, although it is very unlikely that any of the genera now known were the progenitors. The fossils indicate that since the Lower Permian the evolution of this Perlarian line has resulted in the reduction of the number of tarsal segments, the elimination of the prothoracic lobes and the posterior media of the fore wing, the nearly complete loss of the vestiges of an external ovipositor and the lateral abdominal gills of the nymphs and adults. In respect to these and other features the Protoperlaria are intermediate between the true Protorthoptera and Perlaria, for 5-segmented tarsi, prothoracic expansions, an external ovipositor were possessed by at least some of the Protorthoptera The close relationship between the Orthoptera (s. lat) and the Perlaria is now generally recognized by entomologists, and the Perlaria are frequently regarded as Orthoptera which adopted an aquatic mode of existence in the immature stages, forming a divergent branch of the Orthoptera. The Protoperlaria of the Lower Permian appear to represent the beginnings of that divergence."[15]

[14] Throughout his paper Tillyard uses the term *larvae* in a broad sense, i. e , including nymphs

[15] Zeuner (1939, p. 47) has objected to the inclusion of insects with prothoracic expansions in the Protorthoptera on the grounds that "Handlirsch defined the Protorthoptera by the absence of these expansions " I am afraid that he is mistaken in this, for Handlirsch makes no mention of either the absence or presence of

In spite of these statements, which I consider to be clear, Tillyard misconstrued my remarks in his discussion of the Probnisidae, implying that I distinguished between the Protoperlaria and Protorthoptera only by the presence or absence of the ovipositor, and that I attempted to prove a correlation between the absence of a complete external ovipositor and the aquatic habitat of the nymphs He then comes to the conclusion, which he appears to regard as original with him, that the Protoperlaria should be restricted to include "those forms which possessed aquatic larvae [nymphs]" This is precisely the conclusion which I had previously reached

Having adopted this restriction for the Protoperlaria, Tillyard places the Probnisidae in that order His reasons for doing so are given by him as follows

"Now there are nineteen specimens of larvae [nymphs] in the Yale collection Of these one belongs to a large Protorthopteron . The other eighteen are all evidently aquatic types, either complete or nearly so, and they all belong quite as evidently to the Protoperlaria, and not to Plectoptera or Odonata, though both of these Orders also occur in the Kansas beds

"While retaining completed results of my larval study for a later paper, it is necessary to state here that I have been able to recognize two quite distinct types of larvae in the Yale collection over and above those described by Carpenter, and that I feel confident that these two types represent the larvae of the genera *Paraprisca* (Lemmatophoridae) and *Probnis* respectively As *Probnis* is one of the most abundant types represented in the collection, we should expect to find its larva fairly common also, if it were an aquatic types, and such, indeed proves to be the case

"We now have a *prima facie* case for including the Probnisidae within the Protoperlaria They fulfill the definition laid down by me [sic!] earlier in this paper that they should possess aquatic larvae and prothoracic expansions or lobes in the adult "

such expansions in his definition of the order (Die fossilen Insekten, 1906, p 128) Handlirsch's statement about the prothorax is "der Prothorax gross, oft stark verlangert " However, even if it were true that Handlirsch's definition of the order characterized the Protorthoptera by the absence of prothoracic expansions, that would not prevent the inclusion of species with them in the order The concept of any taxonomic category, whether order, family, genus, etc , is continually being changed as new species are found A flexible concept is especially necessary for extinct categories, since our knowledge of them is acquired only by the accumulation of a few facts at infrequent intervals.

I have quoted this passage in full in order to present in Tillyard's own words the evidence for his conclusion. Briefly stated, of course, he claims to have found specimens of aquatic nymphs in the Yale collection which belong to *Probnis*. He gives two reasons for associating these nymphs with the adults of the latter genus 1) Since *Probnis* is one of the most abundant insects represented in the Yale collection, its nymph, if aquatic, ought to be fairly common 2) One of the "common" nymphs with aquatic modifications has an abdominal pattern like that of the adults of *Probnis*

In my opinion, Tillyard was not justified in drawing the conclusions which he reached. Following Tillyard's death, in 1938, the Yale specimens from the Elmo limestone were turned over to me for study by the authorities of the Peabody Museum. Included in a box marked "larval types" are the nymphs to which Tillyard obviously had reference in his paper on the Probnisidae I find in this box twenty-one nymphs (two more having turned up in the collection since Tillyard wrote his account of *Probnis*), of which fifteen are like those described by me as Lemmatophorids, and which obviously belong to that group, as stated by Tillyard The other six specimens comprise the Protorthopteron mentioned by Tillyard and five poorly preserved nymphs which are quite different from the Lemmatophorids These are without doubt the specimens which Tillyard regarded as the young of Probnis Similar nymphs are present in the Harvard collection, but I did not mention them in my account of the immature stages of the Lemmatophoridae, because I felt certain that they did not belong there. All of these nymphs are characterized by having a pigmented pattern on the dorsum of the thorax and abdomen. Tillyard's statement that these nymphs are "fairly common" in the Yale collection is very surprising in view of the actual presence of only five specimens Even in the combined Harvard, Yale and Sellards collections from Elmo, an aggregation of over 10,000 specimens, I find a total of but 15 of these nymphs They appear to me to be very rare rather than fairly common, and as such would hardly fit Tillyard's requirements for the nymphs of *Probnis*, viz , "As *Probnis* is one of the most abundant types represented in the collection, we should expect to find its larva also fairly common if it were an aquatic type." As to the pattern on the abdomen and thorax, I have been completely unable, as stated above, to find any trace of this on the adults of *Probnis*, including the material in the Yale collection There are, of course, the irregular blackened areas caused by the breaking away of part of the carbonized body,

but such areas are nearly always present in all the Elmo insects which have body parts preserved. It is possible that Tillyard misinterpreted the significance of these blackened areas, although one would suppose that he would have noted them in the Lemmatophoridae and other common species Of course, if the adult Probnisidae actually had a mottled pattern on the abdomen even remotely resembling that of the nymphs mentioned, I would consider this strong and even conclusive evidence of the association between the nymphs and the adults

There is one structural feature of the Probnisid adults which indicates that their immature stages were *not* aquatic The adults of the Lemmatophoridae (Protoperlaria) possess lateral abdominal projections which have been interpreted by Tillyard and me (Carpenter, 1935, p 143) as vestiges of the lateral tracheal gills present in the nymphs No such structures occur in the adults of *Probnis*, as was observed by Tillyard Now while it is of course true that the presence of such gill vestiges is not at all necessary in adults having aquatic nymphs, nevertheless their constant presence in all known genera of Protoperlaria would at least lead us to expect them (but not require them) to be present in other members of the group Their absence in the adult Probnisidae is at least an indication, however slim, that these insects did not have aquatic nymphs

If the nymphs of the Probnisidae were terrestrial, then the family is eliminated from the Protoperlaria, as that order has been defined In this connection, it is pertinent to note that a comparison of the structure of the Probnisidae (adults) with that of the Lemmatophoridae, on which the order Protoperlaria was established, gives added support to the view that the Probnisidae are not so closely related to the Lemmatophoridae as Tillyard believed The head of the Probnisids was prognathous, whereas that of the Lemmatophorids was hypognathous, the antennae of the Probnisids were relatively short and stout, whereas those of the Lemmatophorids were very long, slender, and multisegmented, the tarsi of the Probnisidae were 3-segmented and the tibiae were peculiarly modified, whereas the tarsi of the Lemmatophorids were five segmented and the tibiae were normal, the cerci of the Probnisidae were short and had few segments, whereas those of the Lemmatophorids were long and multisegmented. The venation of the Probnisidae is like that of the Lemmatophorids in most respects, it is true, but I have repeatedly pointed out that the venation of the Protoperlaria, as represented by the Lemmatophorids, and that of many of the Permian Protorthoptera are so much alike that it is not possible to distinguish ordinal differences on the wing venation alone

It is my conviction, therefore, that the Probnisidae had terrestrial nymphs and were members of the Order Protorthoptera (suborder Geraroidea) Their closest relatives as far as known were the Lepiidae, a family represented in the Elmo limestone by *Lepium elongatum* Sellards This latter insect, which was referred to the Protorthoptera by Tillyard, will be dealt with in the next part of this series of publications.

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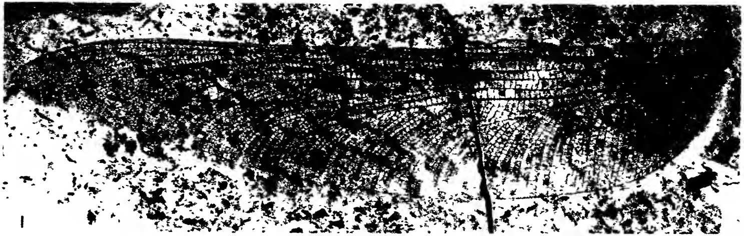
EXPLANATION OF PLATE 1

FIGURE 1. *Megatypus schucherti* Till (x1) Photograph of specimen no. 4633, Museum of Comparative Zoology.

FIGURE 2 *Apsidoneura flexa*, n sp. (x6). Photograph of holotype, no 4572, Museum of Comparative Zoology.



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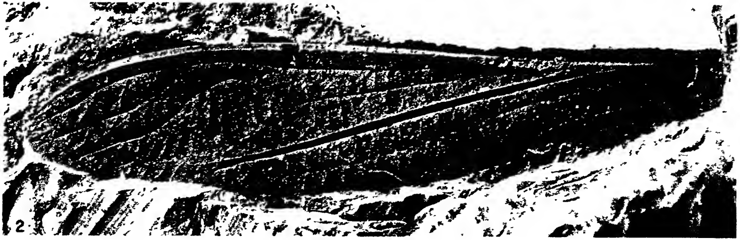

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SOME FACTORS IN THE DEFENSE MECHANISM AGAINST REINFECTION WITH *TRYPANOSOMA LEWISI*

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Early in the experimental studies on *Trypanosoma lewisi* it was discovered that rats having spontaneously recovered from an infection are refractory to reinfection (Kanthack, Durham and Blanford[1]) The immunity thus acquired lasts, with an occasional exception, for the life of the rat The numerous immunological studies with *T. lewisi* have been chiefly centered on determining the factors involved in the recovery of rats from an initial infection (Taliaferro,[2] Regendanz and Kikuth,[3] and others)

Our knowledge of the defense mechanism against reinfection is at present meager and largely based on *in vitro* studies Only a few observations have been made directly on the parasite during the course of reinfection Laveran and Mesnil[4] noted that when recovered or hyperimmunized rats are inoculated intraperitoneally with living *T lewisi* the parasites seldom appear in the circulating blood They believed that phagocytosis was the chief mechanism involved in both active and passive immunity Agglutination of the parasites was observed by Laveran and Mesnil, but they did not consider it an important event in the defense mechanism since the parasites were apparently uninjured by the reaction

Recent workers have generally failed to observe typical phagocytosis of trypanosomes Taliaferro[5] has noted trypanosomes attached to leucocytes under conditions similar to the experiments of Laveran and Mesnil and when inactivated immune rat serum was mixed with washed *T lewisi* and washed guinea pig leucocytes It would appear that, at the present time, phagocytosis is not considered to be the important or usual manner of destruction and disposal of *T lewisi* in either the initial infection or in reinfection

Taliaferro[6] injected intravenously large quantities of washed adult trypanosomes into recovered rats—but otherwise normal—and also into recovered rats splenectomized during the course of their initial infection. In the first experiments, 27 rats were inoculated from 6 to 325 days after the end of the initial infection. There was no apparent correlation between the length of time from recovery to the second inoculation and the duration of the reinfection No reproduction by the parasites was noted in 8 rats whose reinfections lasted from 2 to 3 days Dividing forms occurred in 6 rats whose reinfections lasted 2 to 13 days and, for the others, the trypanosomes remained in the blood too short a time to determine reproductive activity In many of the rats recovery was apparently rapid, since "the parasites were swept from the blood in 5 to 15 minutes" To what extent reproduction developed and whether a numerical increase of trypanosomes occurred is not stated In the splenectomized series, 10 rats were reinfected from 31 to 353 days after the end of the initial infection The reinfections lasted from 1 to 40 days and in 2 rats "slight variation" of trypanosomes but no division was noted It was concluded that, in most cases, the trypanocidal antibody is so strong in recovered rats that it is largely effective before the ablastin (reproduction-inhibiting antibody) has time to play any particular rôle. The nature of the trypanocidal antibody has not been determined, but according to Taliaferro,[6] it is a lytic antibody which may act as an opsonin *in vivo* *In vivo* studies, thus far, have failed to indicate the specific character of this antibody

From a review of the literature it would appear that in most attempts to establish reinfection the experimental animal was injected intraperitoneally with a dilute suspension of infective blood Since trypanosomes injected into the peritoneal cavity must traverse one or more lymph nodes before they can enter the blood stream, the possibility was early considered that in spontaneous recovery the lymph nodes might become "sensitized" and thus produce an effective barrier against the parasites entering the circulation

In the present study, experiments designed to gain information on this question clearly demonstrated that trypanosomes pass without hindrance

and as readily through the lymph nodes of a rat spontaneously recovered from previous infection as they do through the nodes of a normal, susceptible rat (Augustine[7,8]), and that they then appear with equal promptness in the circulation Further *in vivo* studies, herein reported, revealed some phenomena in the defense mechanism against reinfection. From these studies it is apparent that ablastin, the reproduction-inhibiting antibody believed to play an important rôle in recovery from an initial infection,[5] appears to be absent or non-operative in reinfection Rapid recovery from reinfection appears to be due entirely to the action of the trypanocidal antibody, to which the dividing trypanosomes are particularly vulnerable, and by which they are first immobilized or killed and are then phagocytosed by the circulating mononuclear leucocytes, and by which the adult parasites are agglutinated but not killed, and are then mechanically removed from the circulation and destroyed in the liver and probably also in the spleen.

Material and Methods

The present experiments were made with the same strain of trypanosomes (*T lewisi*) used in our earlier studies[7,8] It was originally obtained in 1938 by Dr. E E Tyzzer from a wild rat trapped in South Boston The strain has since been maintained in the laboratory in cultures and in albino rats, originally of Wistar stock, and which are believed to be bartonella-free. The experimental rats were of this same laboratory-bred stock

The procedures in the present series of experiments are essentially the same as those followed in our earlier studies[7,8] The experimental rats were injected with great quantities of trypanosomes. To obtain these, rats, previously inoculated and whose bloods were heavily parasitized, were etherized, the thoracic cavity exposed, and bled to death from the heart into a syringe containing a small amount of heparinized saline The blood was then diluted several times with normal saline and centrifuged at a medium speed until most of the blood cells were thrown down The supernatant fluid was then removed and centrifuged a second time for about twenty minutes at high speed. The supernatant of this centrifugation was discarded and the trypanosomes were collected with the leucocytic layer of the sediment. More saline was added to the remaining sediment of the first centrifugation, which sediment always contained an appreciable number of trypanosomes, and after one or more centrifugations and separations the trypanosomes collected were added to those already obtained. The total number of trypanosomes obtained was estimated by the usual hemocytometer method and the lot was then immediately inoculated into the peritoneal cavity of the experimental rat. The parasites in the experimental rat were studied in fresh samples of blood obtained from the tail or a toe, blood films stained by Wright's method, in fresh teased tissue in saline and in fixed sections of tissue stained with eosin and methylene blue or by Delafield's hematoxylin-eosin method. The degree of reproductive activity was evaluated by determining the percentage of parasites with a divided kinetoplast or nucleus in the stained blood preparations. A total of 200 parasites were carefully examined for evidence of cell division Cells in the process of dividing into two or more units were counted as a single dividing cell

Results

The first series of experiments were performed to determine if lymph nodes become effective filters against trypanosomes as a result of spontaneous recovery from previous infection Four rats (Nos 201, 202, 203, 204) whose initial infections lasted for about 9, 27, 44 and 69 days were each reinoculated intraperitoneally with more than 330 million adult trypanosomes 27, 37, 14 and 68 days, respectively, after the approximate end of their first infections A fifth experimental rat (No. 307) whose initial infection lasted approximately 48 days was similarly reinoculated 112 days later with young trypanosomes undergoing rapid multiplication, the infection in the donor had been allowed to run for 5 days. Samples of blood from all 5 rats taken 5, 15 and 30 minutes following the inoculations were negative The first positive sample was obtained after about 40 minutes from rat 202 and samples from the remaining rats were positive within the first hour The trypanosomes were active and apparently unharmed during their journey from the peritoneal cavity through the lymphatics into the blood stream. Fluid aspirated within 30 hours from the peritoneal cavity of these rats always contained active and apparently normal trypanosomes free from host cells None was found after 48 hours. There was no evidence of their destruction in the peritoneal cavity

A sixth rat, No. 310, whose initial infection lasted about 44 days, was similarly reinoculated with 800 million adult trypanosomes 73 days later Within an hour trypanosomes appeared in the circulation. The blood stream infection was transient, no parasites were found on the following day. Fifty-six days later the rat was again inoculated with 400

million adult trypanosomes. No parasites were seen in the blood samples taken up to 3 hours after the inoculation was made. The rat was then killed by a blow on the base of the skull, its chest opened and the mediastinal lymph nodes examined. Two lower nodes were enlarged and reddish, the nodes directly cephalad to these appeared normal One of the lower nodes was removed and teased apart in normal saline. Upon microscopical examination of the material, the donor's blood cells appeared in vibrating clusters containing one or more active parasites One of the smaller, anterior nodes was then removed and similarly examined The preparation showed normal lymph node structures with the exception of a few trypanosomes all of which appeared normal and were free from any cell attachment. Saline washings from the peritoneal cavity contained myriads of single, normal-appearing trypanosomes

Clumping of the donor's blood cells was not observed in our former experiments,[7,8] where the experimental rat had received but a single inoculation. In the present experiment the experimental animal received on three occasions infective material which always contained an appreciable quantity of the donor's blood cells. The phenomena which followed the third injection suggested the possibility that the successive intraperitoneal injections of the blood cells in the inoculum had caused agglutination in the gland

The following experiment was made to gain information on this very point

Two rats, Nos. 311a and 311b, litter mates weighing approximately 110 grams each, were inoculated with *T. lewisi* cultured on NNN medium The infections were first apparent 6 days later and lasted about 49 days Five days after the end of the infections each rat was inoculated intraperitoneally with 200 million adult trypanosomes, the inoculum purposely contained an appreciable amount of the donors's washed blood cells Four hours after inoculation the rats were killed by a blow on the base of the skull and the mediastinal lymph nodes examined

Two other rats, Nos 312a and 312b, litter mates of 311a and 311b, were, at the beginning of the experiment, given intraperitoneally 2.5 cc of washed blood cells from a normal rat. Similar inoculations were made at 10-day intervals, each rat receiving a total of 6 inoculations. On the fourth day after the last injection these rats were inoculated with 200 million trypanosomes, of the same material as was used for their litter mates and approximately 4 hours later the rats were killed in a similar manner and the mediastinal lymph nodes examined. If, in our earlier experiment (rat 310), agglutination in the node were due to an acquired immunity to the trypanosomes alone, we should expect to observe the phenomenon in the nodes of rats 311a and 311b. If, however, the masses were due to the repeated injections of donor blood cells in the inoculum, we should expect agglutination and retention of parasites in lymph nodes of rats 312a and 312b.

Upon gross examination of the mediastinal lymph nodes, one or both of the paired lower nodes of all four experimental rats were distended and reddish in color from absorption of donor blood cells. The cephalad nodes were normal in appearance These nodes were removed separately and teased apart in saline Upon microscopic examination of the preparations none showed the slightest evidence of agglutination of the donor's cells In every case the trypanosomes moved freely among the blood cells without hindrance It would appear, therefore, that intranodal agglutination of the donor's cells in the case of rat 310 was a singular phenomenon comparable to the occurrence of isoagglutinins and isolysins rarely observed in laboratory animals (Ingebrigtsen,[9] Fishbein,[10] and others).

From the results of these first experiments it can be concluded that *T. lewisi*, when inoculated into the peritoneal cavity of rats spontaneously recovered from a previous infection, readily progresses into the lymphatics, passes without hindrance through the lymph nodes and promptly appears uninjured in the blood stream The filtration accomplished here is, therefore, identical to that which occurs when the parasite is similarly inoculated into normal susceptible rats [7]

Mechanism in Recovery from Reinfection

The following experiments are chiefly concerned with the interactions of host and parasite following the entrance of the trypanosomes into the circulation of the rat recovered from one or more previous infections In the first group the experimental rat was inoculated with adult trypanosomes, i e the infections in the donor rats were all 15 or more days old In the second group the analogous inoculations were made with trypanosomes from infections only a few days old which showed many of the parasites undergoing multiplication.

A typical experiment of the first group was as follows

November 10, 1939. Experiment 4 *

* See Augustine[8] for a detailed account of the initial injection in the experimental rat.

Initial Infection

11.55 A M Experimental rat 4, weight 75 gm , injected intraperitoneally with 250 million adult trypanosomes

12 15 P M Trypanosomes present in drop of blood from tail.

November 12

10 45 A M Multiplication of trypanosomes started Few normal trypanosomes in fluid aspirated from body cavity

November 16

10 00 A M. 185,000 trypanosomes per c mm. blood Rate of reproduction diminished No trypanosomes from peritoneal cavity

January 13, 1940.

Approximate end of initial infection

Reinfection

March 27

11.45 A M. Weight 240 gm Blood negative, 400 million washed adult trypanosomes injected intraperitoneally (second inoculation)

12 45 P M Small drop of blood from tail contains 2 trypanosomes

4 45 P M Less than 5,000 trypanosomes per c mm blood Numerous free, normal-appearing trypanosomes in fluid aspirated from peritoneal cavity

March 28

10 00 A M 15,000 trypanosomes per c mm. blood, normal, no variation in size or shape, no multiplication Many normal trypanosomes in fluid from peritoneal cavity

4 00 P.M No change from that at 10 00 A M

March 29

9 15 A M 20,000 trypanosomes per c.mm blood Some variability in size noted, 0 5 per cent dividing cells A new normal trypanosomes in fluid from peritoneal cavity

2 15 P M No change

9 30 P M No change

March 30

9 00 A M Numerical count unsatisfactory. Clusters consisting of up to 40 to 50 parasites present in blood samples from tail and toes The trypanosomes are attached by their posterior tips, their flagella free (figs. 1 and 2) Smaller formations consisting of 2, 3, 4, and 5 individuals similarly attached and single parasites also present The clusters are free of any attachment to the blood cells. Stained smears show an occasional dividing cell included in the clusters of adult trypanosomes Blood examinations made hourly up to 5 00 P.M show no apparent change No trypanosomes in washings from peritoneal cavity

March 31

1·00 A M Blood samples taken from tail and toes contain many agglutinated masses of trypanosomes and a few single parasites. Stained smear shows one dividing cell containing 4 nuclei and 4 kinetoplasts in an agglutinated mass of adult trypanosomes

2 00 A M to 6 00 P M Samples of blood taken hourly show no apparent change except that fewer trypanosomes were present in the last samples taken

April 1

8 30 A M No large agglutinated masses. A few formations of 2 and 3 individuals and a few single trypanosomes (all active) present

1 00 P M No agglutinated parasites seen in several samples of blood A few single, apparently normal adult forms present

April 2

10 00 A M. No trypanosomes found in many samples of blood Several drops of blood were collected in 3 cc normal saline of which 3 one-month-old rats (litter mates) Nos. M, N and O each received 1 cc intraperitoneally

11 30 A M Rat 4 (the experimental animal) reinoculated intraperitoneally with 380 million washed adult trypanosomes

1 30 P M A few single trypanosomes in sample of blood from tail Fluid aspirated from peritoneal cavity contains myriads of active, apparently normal trypanosomes.

April 3

9 30 A M. No trypanosomes found in several samples of blood taken from the tail and toes. Trypanosomes relatively numerous in fluid aspirated from peritoneal cavity, all normally active Several drops of blood collected in 3 cc normal saline of which 3 rats, Nos P, Q and R (litter mates of Nos. M, N, O) each received 1 cc intraperitoneally Fluid aspirated from peritoneal cavity of rat 4 similarly inoculated in rat S, 2 weeks old

April 4

9.30 A M. No trypanosomes found in samples of blood or in saline washings for peritoneal cavity of rat 4

April 8

2 00 P M. Rat 4 negative Blood samples from rats M, N, O, P, Q and R negative. Blood of rat S swarming with trypanosomes.

April 11.

9:15 A.M Rat 4 negative Blood samples from rats M, N, O, P, Q and R negative Blood of rat S swarming with trypanosomes

April 15.

10 00 A M No change in conditions in all rats from that on April 11.

January 14, 1941

3 00 P M Rat 4 Weight 245 gm Blood negative for trypanosomes. Reinoculated intraperitoneally (third inoculation) with 800 million washed, adult trypanosomes

3 45 P M Trypanosomes in blood sample from tail

January 15

9 00 A M 105,000 trypanosomes per c mm blood No dividing cells Numerous active, normal trypanosomes in fluid aspirated from peritoneal cavity

January 16

9 00 A M 95,000 trypanosomes per c mm blood, 0 5 per cent dividing cells Very few trypanosomes in fluid obtained from peritoneal cavity

January 17

9 00 A M 80,000 per c mm blood in which small agglomerations noted No parasites in fluid from peritoneal cavity

January 18.

9 15 A M Blood samples show trypanosomes agglutinated Single trypanosomes also present

January 19

9 30 A M Blood samples negative Rat killed with ether Autopsy shows no gross pathology, tissues removed and fixed for later study

The experiments of this group quite clearly demonstrate that when recovered rats are injected intraperitoneally with adult trypanosomes the parasites arrive promptly and uninjured into the circulating blood Reinfection may last for a few minutes only in some rats while in others it may last for several days The difference in the duration of reinfection is probably due to differences in titer of the trypanocidal antibody in different animals at the time the transfer is made Reproduction by the parasites usually started where reinfection lasted for 2 days or longer Reproduction was never successful The parasites were agglutinated but not killed in blood stream and then mechanically removed before a numerical increase in the parasite population could be evaluated. It appeared that their destruction might then take place in the liver and spleen by the action of the phagocytic cells of the reticulo-endothelial system.

A study of the stained sections of liver, spleen and bone of rat 4 revealed no pertinent pathology. We could scarcely expect to find evidence of destruction of the parasites in the tissues since several hours may have passed between the disappearance of the parasites from the blood and the killing of the rat for post mortem study

Precise information on the fate of the agglutinated masses of trypanosomes was obtained from a study with experimental rat No 20 This rat was reinoculated about 23 days after the end of its initial infection with more than 900 million washed adult trypanosomes It was killed with ether on the morning of the third day of reinfection at which time the blood was swarming with large agglutinated masses of trypanosomes The rat was immediately autopsied and tissues fixed for later study The spleen was 3 5 cm long, all other organs appeared normal. Bits of liver, spleen and bone marrow teased apart in saline showed fairly numerous active trypanosomes, most of which were single and without attachment to any host cells A few agglutinated masses were present in the preparations of liver and spleen. Stained sections of the liver show normal-appearing trypanosomes in the larger blood vessels while in the small vessels remnants of agglutinated parasites with entangled flagella are present (fig 5) The macrophages show evidence of phagocytic activity but we have not been able to identify any of the inclusions as parts or remnants of trypanosomes Normal-appearing single trypanosomes and small agglomerations of trypanosomes are occasionally found in vessels of the spleen No remnants of the parasite have been identified in the spleen but the amount of cytoplasmic inclusions in the phagocytes is marked No parasites were found in stained sections of the femur or in stained smears of bone marrow

A study of our stained blood smears shows that the parasites started to multiply in every instance where the second or later infection lasted more than 2 days Size variation occurred first which was followed by the appearance of individuals with double nuclei or double kinetoplasts and an occasional cell containing 4 nuclei and 4 kinetoplasts Reproduction was not sufficient to cause numerical increase, as the parasites were agglutinated and removed from the circulation before a numerical increase could be evaluated. Dividing cells are frequently found in the agglutinated masses. No evidence was found, either in the fresh blood preparation or in the stained smears, that the agglutinated mass contained dead parasites. The last trypano-

somes seen in the blood following the disappearance of the agglutinated masses have always been adult forms. They have been few in number, frequently only a single parasite in several fresh preparations and are seldom found in the stained smears Their life span in the blood is short, seldom longer than an hour after the disappearance of the agglutinated masses. The manner of their disposal is not known.

From the results of these and pertinent parts of seventeen other similar experiments it is apparent that when adult trypanosomes are injected into the peritoneal cavity of rats recovered from one or more previous infections they readily enter and progress through the lymphatic system, pass uninjured through lymph nodes and promptly appear in the blood circulation They are then agglutinated, but not killed, in the blood stream and are mechanically filtered out and destroyed in the internal organs When the blood stream infection lasted more than 2 days the trypanosomes invariably started to multiply but the parasites were agglutinated and removed from the circulation before any appreciable increase in numbers occurred It is also apparent from the results obtained here that the trypanocidal antibody is definitely localized in the blood and has no effect upon trypanosomes remaining in the peritoneal cavity

In the above experiments the time in which the parasites were demonstrable in the blood varied from a few minutes to 5 days As a rule, the elapsed time from the end of the initial infection to the second infection showed no correlation with the duration of the second infection Such variation would appear to be due to difference in the ability of different rats to produce and retain trypanocidal antibody, or in other words, differences in the titer of this antibody at the time of reinoculation

Since there was a definite attempt by the parasites to multiply, it seemed likely that successful, or at least an appreciable multiplication in such animals might develop from inoculations made with young, dividing trypanosomes which, as we previously demonstrated,[3] continue to multiply without interruption when transferred to a new, susceptible host The following experiments are concerned with reinfection from dividing trypanosomes and the defense reactions in the immune host.

A typical experiment of this type follows·

April 16, 1940. Experiment 300.

Experimental rat No 312, weight 220 gm., inoculated intraperitoneally with washed adult trypanosomes. A normal infection (initial infection) developed which terminated approximately May 23

January 20, 1941 Weight of rat 215 gm.

10·15 A.M. Inoculated with 400 million trypanosomes collected from a rat with an initial infection 5 days old. 4 0 per cent dividing cells.

11 20 A M Many trypanosomes present in samples of blood from tail.

January 21.

9 30 A M 80,000 trypanosomes per c mm. blood, 4.0 per cent dividing cells, size variation marked

January 22

9 30 A M 85,000 trypanosomes per c mm. blood, 3 0 per cent dividing cells. Size variation marked.

January 23

9 00 A M. 50,000 trypanosomes per c mm. blood, 1 0 per cent dividing cells Size variation marked.

January 24

9 00 A M 55,000 trypanosomes per c mm. blood, 0 5 per cent dividing cells Size variation not prominent

January 25

9 30 A M. Trypanosomes agglutinated, numerical estimation unsatisfactory. Adult trypanosomes only, 0 05 per cent of which show double nuclei

January 26

9 45 A M. Only a single, adult trypanosomes present in several fresh blood samples A total of 9 adult trypanosomes found on two large stained blood smears

Blood samples taken January 27, 29 and February 20 negative The rat was in a weakened condition on February 20 and was found dead the morning of February 23

Experiments of this type show again that trypanosomes, in reinfection, are ultimately agglutinated in the circulation and are then removed from the blood stream. However, where the second inoculation was made from 6 to 18 months after the end of the initial infection the attempt of the parasites to multiply without affecting any appreciable numerical increase was a constant feature It was also characteristic, as in the above experiment, for the percentage of dividing cells to decrease in number on successive examinations and reproduction to stop just prior to the event of agglutination, leaving only adult trypanosomes or rarely a dividing cell in the blood.

The study of the stained blood smears from rat 312 at first appeared to offer an acceptable explanation for this lack of an increase in the number of trypanosomes during the early stages of reinfection.

Blood smears made on January 21 show nothing unusual. On January 22 and 23, however, remnants of trypanosomes, free flagella, undulating membranes with the kinetoplast attached, and ruptured trypanosomes discharging their contents were frequently noted Vestiges indicating that the parasite was undergoing division at the time of its destruction are prominent (figs 3 and 4) It is not possible, however, to determine whether all of the vestiges are derived from dividing cells since, in many instances, the more fragile cell elements, including the nucleus, are degenerate or lacking The vestiges are single, free of any blood cells, they lie next to uninjured trypanosomes and normal blood cells and are more or less evenly distributed over the entire smear. The relative daily frequency of these remnants in a count of 400 trypanosomes for the present experiment is 0 05 per cent January 22, 1 5 per cent January 23, 0 05 January 24, and none on January 25 Thus, their structure and their simultaneous presence and disappearance with dividing parasites support the view that they are derived from cells undergoing, or about to undergo, active division

The above observations suggested a lytic action on the parasite outside the macrophage They also suggested that the dividing cell might be particularly vulnerable to this extracellular lytic action of the antibody, but to which the adult forms remained nonsusceptible until the titer of the antibody increased to a point at which they, the adult trypanosomes, became agglutinated, but not killed in the circulation, and then were mechanically removed from the circulation Further studies, in which the entire course of reinfection in the blood stream was viewed with dark-field illumination showed that, while we were correct in the supposition that the dividing parasites may be affected first by the trypanocidal antibody, the chief mechanism of their destruction was found not to be by extracellular lysis.

In the final group of experiments the trypanosomes were inoculated directly into the heart of the recovered rat. The parasites were thus placed directly in the blood and could be constantly observed throughout the course of the blood stream infection. Fresh, undiluted blood preparations were examined at approximately three-minute intervals with direct and darkfield illumination Blood smears were also made for later study

The following experiment is typical of this group

Rat No. 406 was inoculated intraperitoneally on March 10, 1942, with a few adult *T. lewisi* The infection which developed ran the typical course and terminated about 39 days later On May 5, about the 17th day after the end of the initial infection, trypanosomes were collected from 2 young rats which had been inoculated 4 days earlier with adult parasites. The trypanosomes for these donor rats showed marked size variation with 3 to 4 per cent of the cells undergoing active division The parasites were finally concentrated in 1 cc saline of which 0 5 cc were injected directly into the heart of experimental rat 406, previously etherized As quickly as possible, a very small drop of blood was obtained from the tail of this rat With direct light and the high dry lens of the microscope a number of large trypanosomes were first noted struggling to free themselves from masses of blood platelets Other trypanosomes were single and appeared normal. The preparation was then examined with dark-field illumination. Nothing noteworthy was observed. In the second preparation some agglutinization of the parasites was observed With dark-field illumination several large motionless trypanosomes were seen floating in the serum while others were rapidly being ingested by macrophages Actual seizure of the immobilized trypanosome by a macrophage was not observed, but ingestion always began at the posterior end of the trypanosome, the flagellar end being the last to disappear within the phagocytic cell. Marked agglutination was found in the third preparation with continued phagocytosis of single parasites A very few single parasites, uniform in size, were found in the fourth preparation but none was seen in the fifth and the several subsequent preparations The parasites had been removed from the blood within about 15 minutes

The same experimental rat was then similarly reinjected with the remaining 0 5 cc of the inoculum. The first drop of blood again swarmed with single trypanosomes The same phenomena in recovery were again observed. The rat died about 15 minutes after the injection was made at which time a few single trypanosomes were present in the blood

Blood smears made before and immediately after the first inoculation show nothing of particular note Markedly increased phagocytosis occurs in the later smears, but the cytoplasmic inclusions of the mononuclear leucocytes cannot be identified with certainty as remnants of trypanosomes. Trypanosomes occur frequently within clumps of blood platelets, an observation which would not be considered of importance or noteworthy had living trypanosomes not been seen struggling to free themselves from masses of platelets in the fresh preparations. Remnants of trypanosomes, ruptured cells and free undulating membranes with attached

kinetoplasts are fairly numerous in the second and third smears made As in earlier experiments, these remnants are more or less evenly distributed over the slide, are unattached and the majority indicate that they are vestiges of dividing cells As none of these vestiges was seen in the fresh preparations, particularly looked for here and elsewhere with dark-field illumination, it is believed that they are remnants of the large sensitized or killed trypanosomes seen floating in the fresh preparations which, because of the action of the trypanocidal antibody, have been rendered particularly fragile and have burst on the slide during the technical preparation of the blood smear We obtained no evidence of extracellular lysis of the parasites

Discussion

From the experimental findings just described it is apparent that trypanosomes (*T lewisi*) pass as readily through lymph nodes of immune rats as they do through lymph nodes of a normal, susceptible rat When these parasites are injected intraperitoneally in an immune rat they suffer no apparent injury during a temporary wait in the peritoneal cavity or from passing through its lymph nodes

Reinfection is usually of short duration, lasting, in our experiments, from a few minutes to several days, but usually not longer than 4 days The life span of the parasites in the circulating blood of the immune rat is chiefly determined by two important factors (1) the titer of the trypanocidal antibody and (2) the particular phase of the infection, *i e* age of the parasite, at the time of transfer The results of our experiments indicate that dividing trypanosomes are particularly vulnerable to the trypanocidal antibody They are almost immediately sensitized with it, being killed or at least immobilized, and are then engulfed by blood macrophages Adult trypanosomes, however, appear more resistant to the trypanocidal antibody and are not immobilized or killed by it, but when the titer of the antibody reaches a certain point, the adult parasites are agglutinated and the living, agglutinated masses are then mechanically filtered out and disposed of in the internal organs Dividing cells may also be agglutinated along with adult forms. While we have not been able to recognize vestiges of trypanosomes in tissue macrophages we have found remnants of agglutinated parasites in the small vessels of the liver (fig 5) This evidence and the presence of an increased amount of debris in the Kupffer cells furnish convincing evidence that the agglutinated masses of trypanosomes are removed from the circulation chiefly in the liver, and probably also in the spleen, and that they are finally disposed of in these organs by the phagocytic action of the elements of the reticulo-endothelial system.

Thus, the mechanics in recovery from reinfection with *T. lewisi* are strikingly and fundamentally different from those described in recovery from the initial infection According to Taliaferro,[2] and others, there are three manifestations of resistance against the parasite in the course of the first infection· (1) the retardation and final inhibition of reproduction of the trypanosomes by about the 10th day by a development of an acquired immunity involving an antibody now known as ablastin; (2) a sudden destruction of most of the circulating trypanosomes by the action of a trypanocidal antibody and (3) the total disappearance of the parasites which terminates the infection and occurs from a week to several months after the first drop in numbers Although the specific action of the trypanocidal antibody has not been demonstrated in the whole blood of recovered rats, the current opinion seems to be that it functions as an extracellular lysin.

Our experiments have given no indication that ablastin functions in recovery from reinfection It is true that the parasitic population in the blood of the immune rat does not increase, but this failure is not due to an inhibition of reproductive activity On the contrary, reproduction may be initiated, or may continue for some time in the circulation However, the dividing cells are particularly susceptible to the action of trypanocidal antibody and they succumb as quickly as they are formed. Thus, an increase in the parasite population is checked, but reproductive activity is not inhibited

The results of the present experiments leave little doubt as to the precise functions of the trypanocidal antibody Direct observations have shown that it sensitizes the dividing cells which are thus rendered vulnerable to the phagocytic cells of the blood, and that it agglutinates the adult parasites which are then mechanically removed from the circulation. It is possible that we are dealing with two distinct antibodies, (1) an opsonin which acts specifically on dividing trypanosomes and (2) an agglutinin which agglutinates both adult and dividing forms At present, however, we prefer to regard the trypanocidal antibody as a single sensitizing agent, the different manifestations being due to differences in its titer and to differences in susceptibility of dividing and adult parasites

The results we obtained from experimental rat 4 clearly illustrate how strictly the trypanocidal antibody is localized in the blood. On April 2 this rat had, from all appearances, just recovered from a

previous infection when it was again inoculated intraperitoneally with millions of trypanosomes On the following day fluid aspirated from the peritoneal cavity swarmed with trypanosomes which produced infection when transferred to another rat No trypanosomes were found at the time in the blood of rat 4, nor did the blood carry infection when it was inoculated into young rats From the results of our earlier studies,[7,8] it is obvious that trypanosomes were constantly arriving in the blood from the peritoneal cavity at the time It would, therefore, appear that the titer of the antibody in this hyperimmune animal was particularly high and that the parasites were destroyed as soon as they were exposed to the antibody, *i e* as soon as they entered the blood stream

Summary

Experiments concerning factors in the defense mechanism against reinfection with *Trypanosoma lewisi* are reported It has been shown that this parasite passes readily and uninjured through the lymph nodes of rats spontaneously recovered from a previous infection

It is not apparent that ablastin plays any role in recovery in reinfection The disposal of the trypanosomes depends exclusively on the action of a humoral trypanocidal antibody to which dividing parasites are highly susceptible and to which the adult forms are relatively resistant Dividing cells appear in the circulating blood, but are soon killed or immobilized by the antibody and they are then destroyed in the circulating blood by phagocytosis At a sufficiently high titer of the antibody the adult parasites are agglutinated, but not killed The agglutinated masses of living parasites are mechanically removed from the circulating blood and then destroyed in the liver and probably also in the spleen

The possibility of two distinct trypanocidal antibodies functioning in recovery from reinfection is considered

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PLATE I

FIGS 1, 2, 3, and 4 stained by Wright's method. FIG 5 stained with eosin methylene blue.

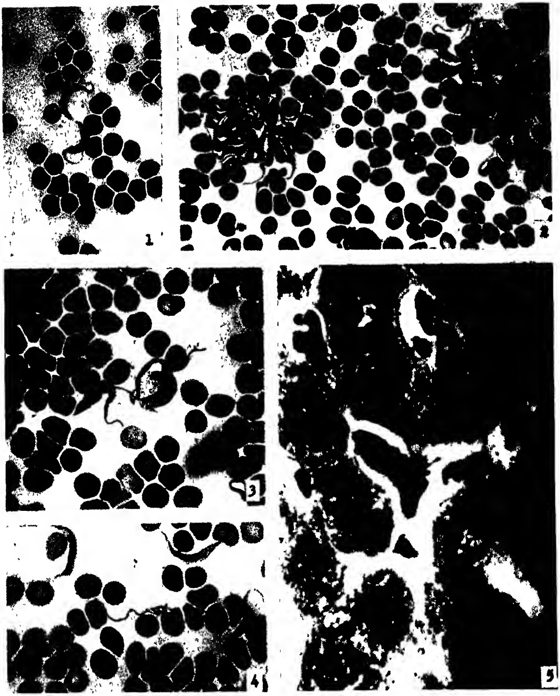
FIG. 1 Agglutination of two trypanosomes showing the characteristic manner of attachment × 900

FIG 2 Two large masses of agglutinated trypanosomes, the attachment slightly distorted by drying of the film × 900

FIG 3 A ruptured dividing trypanosome adjacent to an uninjured adult parasite × 1160

FIG 4 A vestige of a trypanosome showing a lobed kinetoplast and surrounded by uninjured adult parasites × 1160

FIG 5 Section of liver showing remnants of an agglutinated mass of trypanosomes in a blood vessel Only one free flagellum is clearly seen in the photograph × 1600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CHAO HSÜEH-MIN'S OUTLINE OF PYROTECHNICS
A CONTRIBUTION TO THE HISTORY OF FIREWORKS

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Tenney L Davis and Chao Yun-ts'ung 趙雲從

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The history of fireworks is very obscure. It is generally believed that pyrotechnic mixtures of saltpeter with sulfur and charcoal, or with other materials, were invented in China at an early time and were used for entertainment, for purposes of magic as in the exorcising of demons, and later in the military art. A knowledge of these mixtures presumably found its way to Europe over the trade routes to Byzantium The celebrated *Liber ignium ad comburendos hostes* of Marcus Graecus, which was probably written in Greek in the eighth century, describes Greek fire and other incendiaries as well as black powder and the use of the latter material in firecrackers and in primitive rockets without sticks The writings of Roger Bacon in the thirteenth century, which contain what is supposed to be the earliest reference to black powder in Latin Europe, make mention of the fact that toy firecrackers were already in use by the children of the time Modern improvements, the use of chlorate and perchlorate in colored fire compositions, strontium and barium salts to color the flame, and magnesium and aluminum to impart brilliancy, have come in since 1800, they are recent enough to be dated, and certain of them may probably be set down as the inventions of particular men But it is not known who invented the Roman candle, the rocket, the flying pigeon, the catherine wheel and the saxon, and it is not known when or by whom such familiar and much-used substances as arsenic sulfide, antimony sulfide, verdigris, calomel, and iron and steel filings were introduced into pyrotechny

The literature of fireworks is meager Contemporary books in European languages are few and far between, and are issued in such small editions that they quickly become out of print Books before 1800 are rare without exception, but they are especially valuable to students of the history of pyrotechnics for the reason that they antedate modern improvements and indicate the state of the art during a time when it was advancing with exceeding slowness. Fireworks in the eighteenth century were but little advanced over those of the seventeenth century The latter showed considerable improvement over those of Marcus Graecus in the mechanical devices in which they were applied but very little in the materials from which the compositions were made During seven or eight centuries the addition of each new substance to the list of the pyrotechnist's materials must have represented a real achievement

The Chinese text which is under discussion in the present paper is the only Chinese text on civil pyrotechnics[1] which we have been able to find It represents an art which is more highly developed in some respects than the pyrotechnic art of eighteenth century Europe, an art which apparently grew up entirely independently in China It lacks certain things which were common in European treatises, and it mentions certain things which would certainly have been copied in Europe if they had been known It appears to be wholly Chinese

The *Huo-hsi lueh* 火戲略 (Outline of Pyrotechnics) by *Chao Hsueh-min* 趙學敏 is printed in the collection, 昭代叢書[2] where it has a postscript by *Yang Fu-chi* 楊復吉 which is dated 1753 It was therefore in existence at that date A short biography of its author is included in the *Hang-chou fu chih* 杭州府志 (Record of the District of *Hang-chou*) 150 16 b–17a (1923 ed), and considerable information about him and about his father, his brother, and his own work in medicine is given in his two prefaces to his famous Supplement 拾遺, to the *materia medica*, *Pên-ts'ao kang-mu* 本草綱目[3] The prefaces are dated 1770 and 1765, but they contain no reference to their author's age at the time when they were written

Chao Hsueh-min, whose *tzŭ* was *Shu-hsien* 恕軒,

[1] Dr A W Hummel, Chief of the Division of Orientalia, Library of Congress, has kindly directed our attention to two earlier texts on military pyrotechnics, and has made it possible for us to procure microfilms of them We hope to report upon these shortly.

[2] Volume 170 of the edition in the Library of Congress

[3] We wish to make grateful acknowledgment to Dr A W Hummel for giving us references to this material, to Dr. *Ch'iu K'ai-ming* 裘開明 for finding it for us in the Library of the Harvard-Yenching Institute, to the Harvard-Yenching Institute for the use of its text of the *Huo-hsi lüeh* and for the use of the Chinese type which has been employed in the present printing, and to Professor James R Ware of Harvard University for reading the manuscript and for valuable criticism and suggestions.

was a native of *Ch'ien-t'ang* 錢塘 in *Hang-chou* (Chehkiang Province). He lived during the *Ch'ien-lung* 乾隆 era (1736–1796) His father was Salt Commissioner of *Hsia-sha* 下砂 county The story goes that his father longed for sons One day, when he was in *Ching-k'ou* 京口, he met a stranger who said to him, "According to your physiognomy, you will not have any successor, but, if you do beneficial relief work, you may get sons " There was an ocean flood which caused the death of hundreds of thousands of people He did his best to rescue them and to bury the dead In the autumn a plague followed, and he again contributed his salary to help, to procure medicines and the services of physicians Thousands of lives were saved in consequence He also suggested to the government a plan for the building of a dike The officers in charge allowed the plan to be heard by the Emperor, and it was approved Before any action was taken, many fields were badly damaged by the ocean tides, and seven counties, *Hsia-sha*, *Shih-yen* 石堰, *Ch'uan-shan* 穿山, *Ming-hao* 鳴鶴, *Lung-t'ou* 龍頭, etc , were inundated He managed however to build the dike himself, and when it was finished he named it *Li-chi* 利濟 (Beneficial Relief) In the autumn of that year the ocean tides came again, but they were stopped by the dike and no damage was done Later he was moved from this post to hold office in *Yu-ch'i* 尤溪 And so it came about that his sons, *Hsueh-min* and *Ch'iai* 楷 were born, and were given the baby names of *Li* 利 (Beneficial) and *Chi* 濟 (Relief) When the father retired from his post, he also gave his hall the same name of *Li-chi*

The father wished one of his sons to study Confucius and the other to study medicine *Ch'iai*, the younger, studied the teachings of Confucius but also studied the canons on typhoid and on fevers In his leisure time he was taught "to draw the copper man diagrams" [study acupuncture] for fun From spring to winter the brothers studied in the Nourishing Essence Garden 養素園, which was fifty *mou* 畝 of land (more than six acres) devoted to the cultivation of medicinal grasses *Hsüeh-min* encouraged his brother to specialize in medicine (*Ch'i-Huang* 岐黄) in accordance with the wish of his father Although *Ch'iai* did not have confidence enough in himself to practice medicine publicly, relatives and friends who called upon him for diagnosis and who took his medicine were all cured of their diseases. He wrote a work entitled "Mirror of Herbs" 百草鏡 in 8 *chüan* 卷, and another on "Saving Lives from the Ocean of Sorrows" 救生苦海 in 100 *chüan*.

Chao Hsueh-min was a great reader It was his custom to continue his reading into the night. He says that he liked especially to read about the stars and the calendar, about medical subjects, and about divination and alchemy When he found anything which interested him, he was so pleased that he forgot fatigue, he copied it or summarized it, and filed the material in packages. In this way he accumulated several thousand *chuan* In the first of the prefaces which accompany his Supplement 拾遺 to the *Pên-ts'ao kang-mu*, he says that he almost became tired of this kind of work, and that once, when he had the time available to look them over, he picked out those which he thought to be useless and threw them in the furnace He wrote *Li-chi shih-êrh chung* 利濟十二種 (Twelve Books from Li-chi Hall), as follows—

1 The Best Works of the Medical World 醫林集腋, 16 *chuan*,

2 Transmitted Trustworthy Formulas from the Nourishing Essence Garden 養素園傳信方, 6 *chuan*,

3 Proofs of Exorcism 祝由錄驗, 4 *chuan*,

4 Collections 集 under the Names of *Nang* and *Lu* 囊露 (herbs), 4 *chuan*,

5 Observations 話 on the *Pên-ts'ao*, 32 *chüan*,

6. A Gathering of Selected Formulas (of the author and others) 串雅, 8 *chuan*,

7. A Report on the Short Names of Certain Herbs 花藥小名錄, 4 *chuan*,

8 The Secrets of Rising and Sinking 升降祕要, 2 *chuan*,

9 Leisure Readings on the Maintenance of the Health 攝生閒覽, 4 *chuan*,

10 Explanations of the Properties of Medicines 藥性元解, 4 *chuan*,

11 References to Strange Medicines 奇藥備考, 6 *chuan*, and

12 Supplement to *Pên-ts'ao kang-mu*, 10 *chüan*.

The twelve titles were published in the book catalogue of the *Pao* 鮑 family, and the manuscripts were circulated At the end of the *Chia-ch'ing* 嘉慶 era (1796–1821) only the manuscripts of Nos. 6 and 12 survived, and these texts were preserved in the *Hang i lien pao* 杭醫連寶 (The United Treasure of Hangchow Medical Doctors). *Chang Ying-ch'ang* 張應昌 reorganized the material in these two texts, corrected the mistakes, and edited and published them in the middle of the *T'ung-chih* 同治 era (1862–1875) The other ten texts have been lost The manuscripts of the family are said to have been destroyed about 1860 in the Taiping Rebellion

Of the two prefaces by *Chao Hsueh-min* which now accompany his Supplement to the *Pên-ts'ao*

kang-mu, the second is properly a preface to the Supplement and describes his reasons for writing it The first is really a preface to the whole collection of Twelve Books on Beneficial Relief, and tells something of the circumstances surrounding the writing of each of the treatises The author says—

"Of the Twelve Books which I wrote, the manuscripts of two, namely, of the 'Proofs of Exorcism,' and the 'Gathering of Selected Formulas,' were set aside last year to be put on the fire, but the manuscripts were saved by the children The treatise, 'The Best Works of the Medical World,' was completed a year ago Once I happened to have a chance to read the books in the library of my neighbor, *Huang Fan-wêng* 黃販翁, in which the collection of books on medicine amounted to more than ten thousand *chuan*, and I compared them with my old collection of confidential papers of the Kiangsu and Fukien authors I selected from them the formulas which had always proved effective to form a treatise entitled 'Best Works' It was my experience that the selection was not easy Some of my relatives and friends happened to test the formulas, and told me of improvements The treatise was then revised, and enlarged from year to year, and its name was changed to 'Transmitted Trustworthy Formulas'

"In the spring of the year *i-hai* 乙亥 (1755), *Wang Tzŭ-shih* 汪子師 of Hunan Province paid me a visit and made a short stay in my home I saw on his desk a volume on exorcism, the formulas of which he was testing I then borrowed the book and copied it myself, and later secured other manuscripts, those of the *Chang* 張 family, of the *Wan* 萬 family, and of the *Hsieh* 薛 family I tested some of the formulas from them, removed the false ones, saved the effective ones, and wrote the book, 'Proofs of Exorcism'

"I was addicted to the reading of books The daytime was not enough for my study, and I continued it by the burning of fat I disliked to yawn in the study hall, and so I built a box for the lamp and brought it into the mosquito net in order to carry on my reading at night After some time the soot from the lamp blackened the beautiful net In the year *ping-tzŭ* 丙子 (1756) I had eye disease. The disease was so serious that I almost became blind, after six months of sightlessness it was finally cured. For this reason I wrote another book entitled 'Collections under the Names of *Nang* and *Lu*'[4]

"Someday if I can devote my time to studying the canons on the impulse of the blood, on typhoid, on fever, etc, and can organize the material into treatises, I shall write ten more books These, together with the two books written by my brother, I shall put into a 'Later Twelve Books from Li-Chi Hall' The year *kêng-yin* 庚寅 (1770), the second month of spring, the sixth day of the month *Chao Hsüeh-min, Shu-hsien*"

The *Huo-hsi lueh* (Outline of Pyrotechnics) is probably one of the earlier works of *Chao Hsüeh-min*, for the note of commendation appended to it by a reader is dated 1753, more than a decade earlier than the dates (1765 and 1770) which *Chao Hsüeh-min* has himself given his own prefaces to the Supplement to the *P'ên-ts'ao kang-mu*. The treatise appears to be one of those collections of notes, or summaries of readings, of which *Chao* says that he accumulated several thousand *chuan* It shows an acquaintance with the materials of the pyrotechnist, and with their properties and uses, and leads one to believe that its author had handled them himself It appears to consist essentially of the notes and observations of a skilful worker in the art, addressed to one who is already familiar with the principles. It omits many details It does not, for example, tell how saltpeter is prepared, but it indicates a true understanding of the unfavorable effect of sea salt which may be present in it as an impurity It shows an interst in the theoretical basis or explanation of the observed facts It contains no mention of antimony sulfide which was widely used in eighteenth century European pyrotechnics, and conversely it refers to materials and techniques which had not yet been applied in European practice Many of its points of interest are discussed in the notes which follow the Translation and Abstract and which are numbered with the same numbers as the paragraphs of the Translation and Abstract to which they refer

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[4] *Nang* and *Lu* are herbs which are used in the treatment of eye disease

TRANSLATION AND ABSTRACT

HUO HSI LÜEH 火戲略 *AN OUTLINE OF PYROTECHNICS*

By Chao Hsüeh-min 趙學敏

Extraction of Saltpeter

1 [1a–2a] *Hsiao* 硝 (saltpeter) is produced in salty places (salt marshes) The districts in *Ch'ing-yang* 慶陽 (in Kansu) and in *Ho-pei* 河北 (in Honan Province) and the interior of *Shu* 蜀 (*Ssŭ-ch'uan* 四川 Province) have an abundance of this substance. During the autumn and wintertime the ground is covered with a white material which is swept up with a broom and refined by boiling (its solutions), and *hsiao* is thus obtained. In *Ts'ui Fang's* 崔昉 *Wai-tan* 外丹 (exterior *tan*), and in the *Pên ts'ao* 本草 (Book of Medicines), it is called *yin shih* 陰石 (stone of *yin* 陰) In *Fu hung t'u* 伏汞圖 (Diagrams of Conquering Mercury) of *Hu-kang-tzŭ*, 狐剛子 it is also named *pei ti yuan chu* 北帝元珠 (the primary pearl of the Northern God)

2 *Hsiao* (saltpeter) gets its name, I suppose, from the fact that it is the essence of *T'ai yin* 太陰 (the Grand *yin*, synonym of the moon) and will fly away on meeting fire At the extremity of *yin* 陰, *yang* 陽 begins to appear *Hsiao* pertains to *li* 離 (a *kua* 卦, namely ☲, standing for *yin*), and has the property of being able to soften the five metals and to change the seventy-two stones into water

3 The word *hsiao* means to dissolve (to vanish) It (*hsiao*) must be refined for use as an internal medicine The same is true for use in making fireworks It is thought that *hsiao* is formed by the influence of the ethereal essence of the salty sea, since it becomes wet in contact with a humid atmosphere Dryness is essential for *huo yao* 火藥 (fire powder, black powder). If unpurified [1b] *hsiao* is mistakenly used to make the powder, the charcoal of the powder will become moist very easily during humid weather The iron filings (in the powder) will be surely rusted from the effect of the *lu ch'i* 鹵氣 (ethereal essence of salt) caused by the wet charcoal It is unlikely that such a powder can produce any good result in *hua p'ao* 花砲 (flower cannon, flower rocket). Consequently, the *hsiao* must be purified to get rid of the *lu ch'i* (ethereal essence of salt) before it is compounded in the fire-powder

4. For the method employed in the preparation. *hsiao* is put in a large iron kettle, covered with clear water until the water rises one or two *ts'un* 寸 (inches) above the *hsiao*, two *liang* 兩 (ounces) of water glue (glue solution) is added and the contents is boiled for a period of two incenses (the time needed for burning consecutively two pieces of incense) When the liquor boils, foam may form and, in such case, is skimmed off. Remove from the fire and let the liquor stand until clarified On the next day the supernatant liquor is decanted off and is replaced by fresh water. About three or five white turnips are then added and the contents boiled for another two incenses Again, remove from the fire, remove the white turnips, and let the liquor clarify as before Next morning, replace (the supernatant liquor) with fresh water, add new white turnips, and boil the whole again for two incenses The *lu ch'i* (ethereal essence of salt) is completely removed by such treatment The *hsiao* is taken out and dried in the sun light

5 If one wishes to prepare roasted *hsiao*, good *shao chiu* 燒酒 (distilled spirit, samshoo) is added slowly in the kettle to the purified *hsiao* mentioned above, and the contents is roasted to dryness to get the product Another method for manufacturing *hsiao* is given in *Shui shu pên fang* 水鼠本方 (Original Methods of Making Water-Mice)*

Preparation of Sulfur

6 [2a–b] *Huang* 黃 (yellow, sulfur) consists of the essence of pure *yang* 陽 of fire-stone. It is formed by condensing the *ch'i* 氣 (ethereal essence) of the sun Workers in *Wai tan* (Exterior tan), call it *huang ya* 黃芽 (yellow sprout) It is probable that the essence of the sun (sulfur) acquires its body by the influence of wind and wood The branches of wood (the element wood, sulfur) grow out sideways. Therefore, when they are mixed with charcoal, the flames shoot out sideways. Wood appears blue, therefore its flame (the flame of sulfur) is also blue)

7. Sulfur of light yellow color is named *k'un lun huang* 崐崙黃 (the yellow of *K'un-lun* 崐崙); that of red color, *shih t'ing chih* 石亭脂 (the fat of *Shih-t'ing*, red sulfur); that of blue color, *tung chieh shih* 冬結石 (winter-frozen-stone), while that which is half white and half black is called *shên ching shih* 神驚石 (stone of shocking spirits). They are produced everywhere, in the East, the West, the South, and the North. The grade for making rocket powder must be of deep yellow color. If the bluish grey material is used, there will be a hazard of explosion due to its uncleanness. If one

* Water-mice are small fireworks intended for use under water.

wishes to treat it with distilled spirit, do not roast it, but stir it and expose it for drying in the sunlight If it catches fire on roasting with other ingredients, then by using your mouth spray vinegar onto it to stop the fire If you wish [2b] to remove the odor, make a hollow chamber in a white turnip, fill the chamber with the pulverized sulfur, put the white turnip, into a heap of burning rice-hulls until it is cooked, and the odor is gone

8. If you wish to change sulfur into a liquid, fill a bamboo cylinder with your sulfur, bury the cylinder in horse dung for one month and you will get the liquid sulfur This liquid has the characteristic properties of turning the five metals black, of turning mercury red, of giving a purple color with magnetic stone, of making a disturbance with saltpeter, and of becoming quiet with pig fat One should understand these properties and be able to utilize the sulfur well

The Use of Charcoal

9 [2b–3b] Charcoal is the soul 魄 of fire. Fire resides in (the element) wood, and wood comes from (the element) water Whenever wood dies, it turns black to show that it has returned to its original form. The properties of charcoal are to fly away and to give out light easily. It is used in accordance with its properties The charcoal which is usually used for the making of powder is that from the extreme ends of fir branches Other varieties are bamboo shoot charcoal which is violent and spreading, bamboo knot charcoal which is violent and powerful, bamboo root charcoal which is hard and side-bursting, calabash vine charcoal which is quick and side-running, bamboo leaf charcoal which gives a hissing sound, cocoanut [3a] shell charcoal which produces splashing noises, mellon skin charcoal which is quick and violent, eggplant charcoal which makes clear crackling sounds, horn charcoal which is permeable to flame, snake skin charcoal which gives flashing light, and grasshopper charcoal which possesses the property of flying away and running The quick acting powders have the property of destroying and bursting Charcoal from glutinous rice can be used to make bird-gun powder Willow and fir charcoals are the lightest of all and can be used to make powders for *Shou hua* 手花 (hand flowers). *P'ao* 砲 (cannon) using ashes of hemp-stalk (in the powder) produce no noise. If the flinty skin of bamboo is used, plenty of smoke results. Other effects can be produced by applying your knowledge.

10. Charcoal must be prepared by burning (the raw material) until the last trace of smoke is driven off It is then taken out and put into an earthenware jar which has a tight cover. After cooling it is pulverized to the finest degree for use in powder This substance is much disposed to become moist, and so it must be burned (prepared) just before use If too much of it has been made, the unused portion must be wrapped in a piece of paper and put into a jar containing (burnt) lime

11 If the charcoal has been exposed to moist air, it will be unreliable in its effect upon the slowness and quickness of the finished powder, and also it will make the finished powder fail to burn out (produce) colors and flowers. Furthermore, the iron filings will not be completely melted (if used) with such a charcoal

12 However, there is a wet method for making powder. For instance, in the preparation of *chu êrh yao* 珠兒藥 (bead powder), saltpeter is boiled with the charcoal and the (resulting) mass is pulverized when it is still moist In the preparation of *hsüeh têng yao* 雪燈藥 (snow-lantern powder), [3b] camphor is boiled with charcoal and the product is also pulverized while in the moist conditions

13 Another method is the cast-charcoal dry method If you want it (the product) to appear as a silvery thread, (the material) is cast with lacquer and dried in the sunlight whereupon the properties of the powder are stabilized. If you want to change its color, you can drop it (into a kettle), roast it, and cast it It depends upon yourself how much of the subject you can understand

The Use of Iron Filings

14. [3b–4a] *Sha* 砂 (sand, powdered iron) consists of broken cast iron having grains as large as sand, and hence its name Its old name was *t'ieh ê* 鉄蛾 (iron ants) It also has another name, *t'ieh hsieh* 鉄屑 (iron filings) Without it, *t'ung hua* 筒花 (cylinder sparks, cylinder flowers, fountains or gerbs) will no longer produce flowers (sparks).

15. It should be prepared at the time when it is used. It can not be stored for a long time because it has a tendency to rust Once rusted, it will produce no more sparks. Old, broken, cast-iron kettles are usually employed (as the material) for making *sha*. The broken kettles are heated to a red heat in order to remove adhering grease and dirt. After cooling somewhat, they are pulverized in an iron mortar while they are still warm The product is then sieved and separated into four grades. The fines are called upper *sha;* the coarser ones, medium *sha;* the still coarser grade, coarse *sha;* and the coarsest ones are called large *sha* [4a] Besides these, there is another kind of *sha* which is known as

needle *sha*, it consists of drillings from the boring out of needles' eyes After the *sha* is sieved, it is wrapped in paper and put in the lime jar to prevent it from rusting Powdered iron is not to be touched with the hands, otherwise it becomes sparkless rust Oil can also spoil powdered iron as it makes it melt into beads without producing sparks when burnt in powder (compositions) Powdered iron, when weighed, is to be handled with a copper spoon to avoid contact with the hands.

16 At the present time, powdered iron is all purchased from *Su-chou* 蘇州 (near Nanking) It should have a glistening lustre like that of tin

The Match (Fuse)

17 [4a–b] Large match is called double wick match and small match single wick match All kinds come from *Hui-chou* 徽州 (*An-hui* Province, lower Yangtze valley) (where they are manufactured) for use as open-lead igniters for *hua p'ao* (cannon) However, in fireworks there are still other igniters which are known as piped match Matches are of two kinds, the slow ones and the quick ones Quick matches are made with charcoal of calabash, the slow one with charcoal of willow or fir *T'ao hua* 桃花 (peach flower) paper is used as the wrapping paper and should be treated beforehand with a solution of saltpeter (and dried) in the summer time [4b] The powder is wrapped in by twisting the paper around it, and burns readily through a crimp

18 Matches are packed in bundles of 500 pieces each with the two ends of the bundle tied by paper threads They are stored in a lime jar for use at the time needed

19 The powder for matches should be loaded on the paper with a match-spoon in order to get it even The match-spoon is made from a piece of bamboo by cutting the bamboo to a size as small as a scallion leaf and to a length of about one foot in a thin (spoon) shape. When powder is loaded on paper with this spoon, there will be an even distribution of the powder and match of uniform size will thus result

Use of Piped Match (Abstract)

20 [4b–5b] Piped match is a match enclosed in a paper tube, the tube being about the size of a wheat straw and fireproofed with alum In a display of fireworks, piped match is used for connecting the different pieces in order to prevent all of the matches, which cross each other, from burning together at one time, so that the display can be shown in systematic order. Furthermore, the fire of the match is enclosed within the tube and is not visible After the matches have burned, hundreds of flowers of fire appear suddenly, and the display is made much more amusing. The ends of the match are not piped, with the result that the tube, after the match has burned, finds no support for itself and thus drops away.

Treatment of Papers (Abstract)

21 [5b–6b] There are four kinds of papers used in making fireworks, fire-proof paper, inflammable paper, paper for a sharp crackling explosion, and paper for strength. Fire-proof paper is used in making the inner cylinders of fireworks, and is itself made by treating paper with alum solutions. In wrapping fuses, the paper must be inflammable; this result is secured by soaking it in saltpeter solution For firecrackers the paper must be readily torn into small pieces by the explosion to produce loud, cracking reports with small fragments of paper filling the air Bamboo or mulberry-bark paper will be suitable for this purpose For a certain kind of flower cylinder (fountain), the outer layer of the cylinder must be made of strong paper to prevent the bursting of the cylinder, and for this purpose a layer of thick paper or *yüan-shu* 元書 paper is usually used

22. [6a–8] Dyed paper must not be used in fireworks, because the color is likely to be destroyed by the powder If color must be applied, the pigments which are used for ordinary painting will produce satisfactory results and will not be changed by contact with the sulfur fumes

The Containers

23 [6b–7a] Containers are of three different sorts, namely, the clay cylinder, the paper cylinder, and the iron cylinder For *p'ao* (cannon, firecrackers), only the first two are in use while all of the three are employed in flower cylinders (fountains). The mouth and the bottom of a cannon cylinder are equal in size, but in a fountain cylinder the mouth is small and the bottom is large forming a horn-shaped (or conical) space in between. (The conical container) will direct the force of the powder upward without being itself burst.

24. To test fountain powders there is a simple method for making the container. A small bamboo cylinder is cut off so that one of its ends retains the knot and the other is left open The powder is packed into the cylinder until it is almost full. The open end is then blocked tightly with a choke of ashes wrapped in paper [7a] A hole is made through the knot of the other end for inserting a fuse This method obviously saves the laborous effort of mak-

ing a paper container However, before packing in the powder, the cylinder must be packed with paper to make an inner horn-shaped (or conical) cavity with the tip (apex) against the knot This removes the trouble of cracking or side-bursting If a horn-shape cavity is made in a piece of dry clay and the clay is used (in the place of the paper) for packing the bamboo cylinder, the result will be the same

The Compounding

25 [7a–8b] The most essential materials used in the compounding (of the powder) are the saltpeter, sulfur, and charcoal which have been discussed in detail previously Others are auxiliary substances However, one has to know the art of compounding For instance, if *hsiung huang* 雄黃 (male yellow, realgar) or *shih huang* 石黃 (stone yellow, orpiment) is used, (the mineral) must be first stirred with *shao chiu* (distilled spirit) and dried in the sunlight It will give a yellow smoke If it is used together with saltpeter, the smoke will be very intense with a yellow light which will not be overshadowed by the light of the burning powder If sulfur, which has an odor, is employed, it must be roasted with vinegar beforehand in order [7b] to remove the odor By being admixed with *tsao chio kao* 皁角膏 (a fat from the pods of *gleditschia sinensis*), the powder acquires slowness By being mixed with *fu jung chih* 芙蓉汁 (the juice of lotus flowers), the powder becomes quick acting Shreds of cotton give a violet light *t'ung ch'ing* 銅青 (copper green, verdigris, basic acetate of copper) produces a green light, *yin chu* 銀硃 (vermilion, cinnabar), a red light (smoke?), *ch'ien fên* 鉛粉 (lead powder, white lead, carbonate of lead), a white light (smoke?), *hsiung ching* 雄精 (realgar), a yellow light (smoke?), and *sung mei* 松煤 (pine soot), a black light (smoke?) The above contain the five colors of light (smoke?)

26 *Shih huang* 石黃 (orpiment) produces a yellow smoke, *ch'ing tai* 青黛 (lapis lazuli) a green smoke, *chu sha* 硃砂 (cinnabar) a red smoke, *ni fên* 膩粉 (greasy powder, calomel) a white smoke, and *li ch'ing* 瀝青 (pitch, resin) a black smoke The addition of gold or silver foil makes a light similar to that of gold fragments The addition of tin foil makes a light resembling that of broken red clouds Sulfur alone makes it (the light) blue, while the addition of *tan fan* 膽礬 (bluestone, blue vitriol, copper sulfate) makes the light still stronger Saltpeter alone renders the light violet *P'i shih* 砒石 (white arsenic, arsenious acid) produces a still longer light (flame) *Shih nao yu* 石腦油 (rock oil, bitumen, asphalt), *chang nao* 樟腦 (camphor), and *ti sou* 地溲 (earth-extract) all can produce fire from water (liquid) The thorns of *gleditschia sinensis*, spring-willow-branches, bamboo shoots etc , all are able to produce something else in the fire The presence of impurities in the root (the powder) is due to the incomplete extraction of the saltpeter The feebleness of the flowers (sparks) is caused by the use of unfresh (deteriorated) iron filings

27 If one wishes the powder to produce fruits, the spraying of water should be so plentiful as to be comparable to that of spring time If you want the light to be controllable, (the powder) should be stirred with a bath of plums Earthworm powder and snake skin are used according to their properties [8a] Boiling in a solution and drying in the sunlight will bring out the efficacy The persons who are able to do the job will not be limited by a single rule The followers (students) should be able to derive everything from the above (discussion)

28 The proportions (quantities) must be accurate and the mixing must be thorough Iron filings are of coarse and fine grades (The addition of) charcoal has its own order When the roasting method is used, the ingredients must be roasted separately If the wet method should be chosen, the procedures would not be the same The crushing and grinding apparatus should be in good condition and efficient During the sieving, precautions must be taken with respect to wind and fire Follow these rules and you will have over one-half of your thought (more than half of the expected results)

The Roasting of Powder

29 [8a–b] In making powder there is an excellent method of combining the advantages of water and fire For example, *ch'iang yao* 鎗藥 (gunpowder) is made by boiling saltpeter and sulfur with water, roasting (the product) with charcoal and stirring to form the beads *Huo chiu* 火酒 (fire spirit, alcohol) is sometimes used in the roasting According to *Shui shu fang* 水鼠方 (Water and Mice Methods) of *Yün ch'i* 雲溪 (Cloud-spring) floating (upper) saltpeter, jumping saltpeter, and settled (bottom) saltpeter are recommended In *Jên yüan fang* 仁源方 (Spring of Kindness Methods), alcoholic saltpeter is employed to make the five-color butterfly A certain one roasts (the powder) with oil, lacquer, snake-blood, or juice of *fu jung* 芙蓉 (lotus flowers) Again, another roasts in the dry state or roasts with addition of other substances Probably, the advantage of dry roasting is to absorb the power of fire for assisting the rising property (of the powder), while that of admixing with other substances is to make use of the power of

those substances to conform to the will of the *shên ming* 神明 (spirits).

30. There is no definite method If you want to minimize the yellow flame, *tan fan* 胆礬 (bluestone) will be mixed in. If you want to retain the light of saltpeter, (the powder) is to be boiled with rosin oil. If you want the powder whirling around, tails of grubs will be added during the roasting If you want the powder to be spreading, earthworm blood will be added during the roasting. When silver foil is roasted for use in powder, ash of lotus leaves is to be added When copper foil is roasted for use in powder, walnut ashes are to be incorporated The reason is for controlling (the effect).

Miscellaneous Substances (Abstract)

31 [8b–10a] Common people know only that substances which are inflammable can be incorporated into fire powder However, the non-inflammable materials, when used properly, produce wonderful results This has been stated in the Books of *Tan*, that all substances can produce light. It is the substance of inflammable material and the spirit of non-inflammable which are effective For instance, minerals such as *huang tan* 黃丹 (minium, red lead oxide), *mi t'o sêng* 蜜陀僧 (litharge) and *hei hsi hui* 黑錫灰 (black tin ash, lead), all are heavy and are able to suppress the power of the powder. *Ku ch'ing ch'ien* 古靑錢 (old copper coins, old brass), *t'ieh hua fên* 鉄華粉 (acetate of iron) and silver rust are able to split fire to give flowers. *Lu kan shih* 爐甘石 (zinc bloom, zinc carbonate), *pu hui mu* 不灰木 (non-ashing wood, asbestos) and *shih chih kao* 石脂膏 (stone fat, siliceous clay) can be used to treat paper and to separate fire *Ch'ing fên* 輕粉 (calomel), *chung ju* 鍾乳 (stalacitites, chiefly calcite), and *shih t'an* 石炭 (graphite) are able in certain cases to produce particular effects *Yü shih* 礜石 (arsenolite, white arsenical ore), *huang fan* 黃礬 (yellow-colored alum), and *lei mo* 雷墨 (meteorites) all are able to invert the light. *Nao sha* 硇砂 (sal ammoniac), *p'êng sha* 蓬砂 (borax), and salt assist saltpeter and sulfur in the powder to burn out.

32 As for vegetable materials, (the charcoal of) rush stalks can change a small fire into a large one. Rosin can concentrate spreading light into spot light. (Numerous other effects of various vegetables and animal materials are also mentioned)

The Use of Powders (Abstract)

33. [10a–11a] If you want the piece to fly, the addition of mice-powder is necessary If you want it bright, moon-lantern-powder should be added. Powders for filling soft containers are usually fine and are not quick-acting. If quick-acting powder is used (in this case), the container will be shattered and your hand may be injured. The flowers of soft pieces must shoot out sidewise and open slantingly, otherwise the choke will be blasted out and random burning result from the straight-upward shooting. With a large proportion of saltpeter, the force of the powder is tremendous. With plenty of charcoal, the light of the powder becomes scattering. Powders rich in sulfur make loud sounds, while those rich in powdered iron give obscure (unclear) flowers. The shaking of the container (unevenness of firing) is caused by the formation of obstructions in the mouth. The formation of beads on top of the flowers is caused by the use of rusted iron filings.

The Coatings and Pastes

34. [11a–b] It is necessary to know the use of coatings and pastes, for, by means of these, results from the powder are made much more wonderful and changeable. They are comparable to the color designs of a painter and to the pattern designs of a textile-maker If a powder does not have a coating or paste, it will not be able to trace out its flight, and the weak and intense colors are not to be distinguished It will also fail to concentrate the light, and the wonders of the changes will not be magnificent. This subject, therefore, ought to be discussed.

35 Whenever the grains of a powder have no particular shapes, the grains are called beads Those which have corners, are called prisms They may have the shape of grain-awns, chelae, hair, the scars of the moon, a broken wall, a broken sword, fractured calcite, or a heap of hooks They may contain eight corners, a trident, a conical shape, or a shape of a bowl-head

36 Some of these grains are shaped (molded) with open fire, with greenish fire, with explosion-powder, or with ignition-powder It has been stated that powders which have a shape, can put on clothes Red clothes (coating) consists of *chu sha* 硃砂 (cinnabar), green coating, of sulfur; blue coatings, of *t'ung lü* 銅綠 (verdigris, green copper), white coating, of *ch'ien fên* 鉛粉 (lead powder, white lead), and coatings of other colors will be made up in a comparable manner

37. Some people use a paste. For example, when cotton is coated with a sulfur paste, (and is used in the powder), the fire with purple-green balls will fly out. When tin foil treated with a saltpeter-sulfur paste is used, one can see the fire spitting out colored light (flames). If wick-grass is used in the powder, the paste-method must be applied. Some-

times powdered iron is also coated or pasted. When this is used in fountains, the flowers are much more deceptive and marvelous. Again, some one uses powder to coat upon the coat, a paste upon the coat, one side with coat while the other with paste, or coating and paste in the center In another method, the grains of the powder are dressed (coated), made into shape, wrapped together, and coated again This is called the seven-star coating The method of using one layer of coating, then one layer of powder, and so on, layer after layer, is called case-coating. Sometimes, the pipe of a piped match is also coated or pasted This kind of trick is not understood by those who have not specialized in the art.

The Packing in of the Powder (Abstract)

38. [12a–b] To save labor, the powder for firecrackers is loaded into 300–500 small, colored cylinders at one time, all of the cylinders being made up into an hexagonal bundle with the openings facing upward, and the powder is then run in from a long spoon (funnel) In packing fountains, the powder, after loading, must be stirred to prevent the settling down of the powdered iron, and is not to be shaken, otherwise, the ingredients will be separated from each other with the charcoal on top, and the saltpeter and sulfur at the bottom The powder for crackers must be packed loosely but the powder for fountains is pressed hard

Auxiliary Shows (Special Pieces) (Abstract)

39. [12b–13b] The Hundred Sons, The Three Ranks, The First of All, Lucky Clouds, Butterflies, Rockets, Flowers of the Moon, Brick Flowers, The Nine Dragons, the Eight *Hsien* 仙 (immortals), etc , are auxiliary shows (special pieces) They may be fired singly or may make up a part of a play. They go up in the air, jump on the ground, and fly to the one side or dance on the other These furnish motions in front of a stationary spectacle Rockets are the eyes of fireworks, and are fired before the main display in order to quieten the audience.

40. There are some fireworks for display in the day time. They are called smoke-plays, and make use of smokes. They may be so constructed as to display colored buildings, towers, human beings, mountains, waters, and various spectacles The auxiliary shows (special pieces) may be earth mice (ground mice), water mice, snow crackers, smoke crackers, incense lanterns, falling pearls, smoke horns, foggy orchids (orchids of mist or smoke), colored wheels, colored wings, etc , while colored rockets are used as the first fire The flower shells are shells filled with powder for enlarging the shows and are to be reckoned as special pieces Shells of fruits, nuts, fir cones, calabash, paper, clay, wood, etc., are also used.

Flexible Pieces (Abstract)

41. [13b–14b] Flexible articles are constructed by using folding frames on which images of men and other things, buildings, towers, etc., can be mounted at will to form a spectacle. The frames are made of bamboo, hemp-rope, and paper There are self-illuminated figures and figures to be illuminated. Fire wheels, fountains, crackers, rockets, flower-moons, flying rats, etc , may also be mounted on the same frames Fireproof materials are always procured by treating with alum solutions.

Fireproof Screens (Abstract)

42. [14b–15b] When three or four spectacles or displays are mounted and folded up into one package, the bottom spectacle must be separated from the upper one by means of a screen of fireproof paper in order to prevent them from burning together After the display has been exhibited, the screen is dropped off automatically If alum alone is not sufficient to make the paper fire-proof, *lu kan shih* 爐甘石 (zinc bloom, zinc carbonate), *shih chih fên* 石脂粉 (fuller's earth) or lime may also be used in combination with it

Head Fuses (Abstract)

43 [15b–16a] If a fire show is lighted at the bottom, the fire goes upward slowly The difficulty is reduced by lighting it at the top also, so that it takes fire all over This is done by means of head fuse or top match

Rigid Pieces (Abstract)

44 [16b–17a] A rigid piece is used when there is only a single spectacle which does not need to be folded up.

Changing Shows or Transformations (Abstract)

45. [17a–b] The appearance of one thing which will change into another in a show, is called a changing show or transformation Examples are: a fish changing into a dragon, a copper coin changing into a butterfly, the two *hsien* (immortals) giving *tao* 道, the two dragons playing with the ocean (the latter two items have two things change into one), the flat peach, and the god of longevity, and others.

Multiple Pieces (Abstract)

46. [17b–18a] In fireworks displays two or more sets of articles are sometimes fired separately and at

the same time in adjacent scenes to make up one spectacle. They are called combinations.

Flying Pieces (Abstract)

47 [18a–b] *Liu hsing* 流星 (flying star, rocket), flying rat, flower-moon, etc. are the small flying pieces In plays, for instance, the *hsien*-people (immortals) hailing the crane, the envoy *Hsiao* 蕭 riding on the phoenix's back, the golden lotus bursting out from the ground, the five old men going back to heaven, etc are the flying articles of larger designs

Water Fireworks (Abstract)

48 [19a] Powder is put in pig's intestines, paper swans, bamboo cylinders, etc to make fireworks which are fired on the surface of water. Colored smokes and water-mice are fired under the water

Moving Pieces for Banquets (Abstract)

49 [19a–b] Small articles such as jumping grasshoppers, wandering fish, running snakes, galloping deer, etc , all of these being small pieces about an inch in length, are fired after a banquet It is supposed that their smoke facilitates recovery from over-indulgence.

Folding Frames (Abstract)

50 [19b–20a] Folding frames in the form of leaves are made of iron wires They can be folded over for the mounting of fireworks

Assembling the Display (Abstract)

51 [20a–b] Pieces are fastened onto the frame with bamboo fibers or paper-wrapped iron wires, but not with hemp rope, for the latter slips

Connections (Abstract)

52 [20b–21b] There are internal connections and external connections The internal ones use powder while the external ones use match

TABOOS

53 [22a] Essentially, no precautions are needed in the use of *huo hsi* 火戲 (fire-plays, fireworks), but, because of their violent character and light producing ability, wherein they resemble the sunshine on all the devils, they are not to be treated carelessly Although *ni yün* 尼絨 (woolen cloth) and *ching pu* 經布 (muslin) can stop the shooting of a candle, and iron shots and magnetic stones are able to control sulfur, these are the specific properties of the substances, but human actions also accomplish their effects

54 The compounding must not be done in a family which is in mourning. It is especially prohibited in the house where a funeral has been held or where a man has died, for there the misfortune of accidental fire is certain to happen [5] In case the mourning is for someone outside of the immediate family, and in case the family wishes to buy powder and must use it, a piece of red silk-cloth may be hung in the compounding room to release (the family) from the prohibition of using powder In a house where fireworks are being made, one must not burn *ts'an sha* 蠶沙 (grass?) or bamboo leaves lest by this means the essence of the saltpeter is weakened.

55 During the packing of powder, if a drum is beaten to strike power into the powder, the fire-flowers will be brighter However, during the compounding, the sound of a drum must not be heard lest the powder in consequence acquire the defect of bursting The ashes on the charcoal must be removed before use If [22b] a charcoal with adhering ashes is used, the resulting powder will usually be impeded Probably the ashes are the ghosts of charcoal and the charcoal is afraid of them

56 Women are not allowed to handle the powder. If the powder is packed by women, the crackers will change into fountains and vice versa. Smoking is forbidden in the powder room The room should be kept quiet and neat, and noisy talk forbidden in order that the soul of the powder may be soothed. Care must be taken to prevent any changes in the powder. The testing of powder must not be carried out at any place near the powder house The filling of the cylinders must not be done near any fire or smoke The apparatus for handling the powder must be closed tightly, and the access of wind must be prevented. After long standing in the wind, the powder takes fire spontaneously Artifices after being loaded with powder, must not be heated again (for drying), for there is danger that the powder may show its behavior spontaneously after long-continued warming The tamping or pounding of the powder must be neither too heavy nor too light, and the amount of the powder may not freely be increased or decreased. The packing of powder by lamplight is not permissible The opening of the powder container on a rainy day is not permissible. Those who hold established formulas will be limited by them, who understands elemental changes?

[5] Fireworks, especially crackers, are used in China solely for celebrations or for the purpose of expressing joy, and are avoided in times of sadness They are supposed to have the power of driving devils away.

Skill of Craftsmanship (Abstract)

57. [22b] The various operations, the fastening of the artifices, the connecting of the fuses, the preparation of the powder, the tamping in of the charges, etc., all require special tricks of manipulation

The Spare Pole (Abstract)

58 [23b] A stick or pole is useful in case some of the hanging pieces misfire or burn improperly.

A NOTE ON READING THE TREATISE HUO HSI LUEH

By *Yang Fu-chi* 楊復吉

[24a] An account of fireworks has rarely been published. The only available information appears in *Yueh ling kuang i* 月令廣義 (The *Yueh-ling* Expanded, by *Fêng Ying-ching*: 馮應京) and in *Wan shu chih* 宛署記 (Memoranda of *Wan-shu*), both of which were written in the *Ming* 明 dynasty These contain only a few words (on fireworks), and are of little use *Chao Hsüeh-min* 趙學敏 of *Ch'ien-t'ang* 錢塘, giving himself to relating in detail the formulas for manufacturing fireworks, has prepared a book Although the subject is trifling, much energy and patience has gone into the collecting and assembling of materials. The work really occupies a place which has never before been filled By no means should we laugh a bit at this composition as useless *Yang Fu-chi* of *Chên-tsê* 震澤, in the late summer of the year *kuei-yu* 癸酉 (1753)

NOTES

1 *Chao's* description of the purification of saltpeter is so incomplete that one is tempted to infer that he had had no experience with the process No effort appears to have been made to supply the deficiency of potassium in the crude material, or to replace the calcium which is commonly present, as is done in Europe by the use of wood ashes

2. It is interesting to find that saltpeter, the oxidizing agent, is related in Chinese chemistry of the eighteenth century to the negative principle, *yin*, as oxygen in Europe was considered to be dephlogisticated air, and that sulfur in China was the embodiment of the positive principle, phlogiston, the essence of pure *yang*

3 Unpurified saltpeter containing sea salt is more hygroscopic than the purified material Impure saltpeter encourages charcoal (with which it is mixed) to take up moisture, and iron filings to rust

4. The clarification by means of glue would work White turnips boiled in the solution of impure saltpeter would absorb a certain amount of the dissolved salts, and conceivably might, as the text suggests, remove the chlorides faster than the nitrates—but we have no information on this point

8 The process which is here described for the preparation of liquid sulfur might well yield a solution of ammonium polysulfide which would have several of the characteristic properties of sulfur It would, for example, blacken the common metals including mercury, and would also convert mercury into cinnabar by suitable manipulation The other reactions which are enumerated are not so evident, the purple color with magnetic stone and the disturbance with saltpeter, for ammonium polysulfide solution does not react with saltpeter With pig fat it would emulsify to form a salve or ointment

10 Charcoal is hygroscopic. *Chao* recommends that it be kept, as we would say, "in a desiccator over lime."

11 Charcoal which has taken up water makes the compositions which contain it unreliable in their performance

12 The wet method of making black powder, particular sulfurless gunpowder, is at present in use in this country. The text apparently refers to sulfurless gunpowder Particles of charcoal impregnated with camphor (snow-lantern-powder) would produce an interesting effect when used in gerbs or fountains.

13 The powder is mixed with lacquer and cast, the resulting mass is not affected by moisture, and is stable in its properties No analogous method was in use in Europe

14, 15 Powdered cast iron and steel dust were used in Europe at this time, and mixtures containing powdered cast iron were generally called Chinese fire. Lieutenant Robert Jones, contemporary with *Chao*, reports the following formulas

"For a Brilliant Fire Meal powder twelve pound, saltpeter one pound, brimstone four ounces, and steel dust one pound and a half

"Chinese Fire Saltpeter twelve ounces, meal powder two pound, brimstone one pound two ounces, and beat iron twelve ounces

"For Gerbes Meal powder six pound, and beat iron two pound one ounce and a half "[6]

The same author gives six compositions "for standing or fixed cases" (fountains) of which two contain steel dust Needle steel (drillings from the manufacture of needles) are used in gerbs in this country at present.

[6] Jones, "Artificial Fire-Works, Improved to the Modern Practice, From the Minutest to the Highest Branches," etc., 2nd ed., London, 1766, pp. 43, 44.

Cutbush states that "D'Incarville, a missionary at Pekin, obtained the process for making Chinese fire; and observes, that the pulverized cast iron they employ is called *iron-sand*, of which they have six numbers or varieties [7] . . .

"The Chinese have long been in possession of a method of rendering fire brilliant, and variegated in its colours. Cast-iron, reduced to a powder more or less fine, is called iron-sand, because it answers to the name given to it by the Chinese They use old iron pots, which they pulverize, till the grains are not larger than radish seed; and these they separate into sizes or numbers, for particular purposes "[8]

Chao's text indicates a real understanding of the properties of powdered iron, and mentions several wise precautions to be exercised in its handling The practice of wrapping the powder in paper and keeping in a desiccator over lime is a good one, but it does not guarantee the keeping qualities of the mixtures in which the iron is subsequently used Cutbush however recommends a somewhat similar method of storage. "As the goodness of iron or steel dust, in fire-works, depends greatly on its being dry, and not oxidized or rusted; its preservation must be accordingly attended to The usual preservative is to put it in a box, lined with oiled paper, and covered with the same, or in tin cannisters, with their mouths well closed.[9] . . .

"It should be observed, that rockets, into the composition of which, iron-filings and iron-sand enter, cannot be long preserved, owing to the change which the iron undergoes in consequence of moisture."[10]

On the subject of preserving steel and iron filings, Jones says—"It sometimes may happen, that fireworks may be required to be kept a long time, or sent abroad, neither of which could be done with brilliant fires, if made with filings unprepared, for this reason, that the saltpeter being of a damp nature, it causes the iron to rust, the consequence of which is, that when the works are fired, there will appear but very few brilliant sparks, but instead of them a number of red and drossy sparks, and besides, the charge will be so much weakened, that if this should happen to wheels, the fire will hardly be strong enough to force them round, but to prevent such accidents, prepare your filings after the following manner "[11]

He then describes the process of coating the filings with sulfur by stirring them up with melted brimstone. This method was commonly used in Europe as late as the first half of the nineteenth century, but it is more usual now to coat the filings with beeswax, paraffin, or linseed oil

17 Different kinds of charcoal for quick and for slow match.

18 The match is kept dry by means of lime.

20 The trick of leaving the ends of the match unpiped, and thus of causing the match tube or pipe to fall away from the piece after the match has burned, is one which does not appear to have been used in Europe The piped match burns almost instantaneously, but the portion of the match which is not enclosed within the tube burns slowly.

21. The use of alum for fireproofing was ancient and widespread Archelaos, one of the generals of Mithradates in the war with Rome in 87 B. C fireproofed a wooden tower by means of alum, and the wooden siege engines which the Romans used in the war of Constantine and the Persians in 296 A. D. were similarly treated.[12]

22. Many kinds of dyed paper are bleached by the sulfur which is used in the compositions, but the common pigments are generally not affected.

23, 24. The Chinese technique in the making of fountains is described The conical shape of the interior of the container provides what amounts to the choke or constricted exit for the gases in European practice.

25 Orpiment and realgar, sulfides of arsenic which occur naturally as minerals, were used in European compositions at an early date. They are combustible and burn with a bright, white light They are also volatile, and yield yellow smokes to the extent that they escape combustion The intent of the statement that shreds of cotton give violet light is not clear. Verdigris does impart a greenish or bluish color to the flame, especially if chlorides are present; lead compounds tend to give a lilac color; but black *light* from pine soot is obviously impossible. It is probable that the word, light, applied to the effects of verdigris, vermilion, white lead, and pine soot, is in error and that the appearance, like a smoke puff, of a cloud of the finely powdered material, blown about by the force of the burning composition, is really intended.

26. The lapis lazuli, cinnabar, and calomel are evidently intended to be used in the state of fine powders to produce colored clouds of dust, and the

[7] James Cutbush, "A System of Pyrotechny, Comprehending the Theory and Practice," etc, Philadelphia, 1825, p 202

[8] *Ibid.*, p 371.

[9] Cutbush, *op cit*, p. 202

[10] *Ibid.*, pp. 371–372

[11] Jones, *op. cit*, p. 83.

[12] Partington, "Origins and Development of Applied Chemistry", London, New York, Toronto, 1935, p. 148.

metal foils, gold, silver, and tin, to be blown out in the same way as the colored powders to produce interesting visual effects. Pitch burns to produce soot or black smoke. Calomel is volatile and will produce a white smoke; it is used occasionally at present, particularly in blue lights, to supply chlorine which enhances the blue color which copper compounds give to the flame Potassium nitrate (saltpeter) mixed with combustible materials gives a violet flame, sodium nitrate a yellow one.

29 The wet method of making black powder is described, and explanations given of the effects of dry roasting and of wet roasting with the admixture of other substances.

30 A copper compound to reduce the yellowness of the flame. If the powder is boiled with rosin oil (possibly turpentine), its flame will be smaller in size but more lasting in time.

31. There are certain incombustible substances which are useful in the pyrotechnic art for the production of various effects

32. Rosin can "concentrate spreading light into spot light" by preventing an explosive expansion of the mixture in which it is incorporated

33. Mice-powder and moon-lantern-powder are special powders for use in particular fireworks. The author makes practical observations which suggest that he has had an extensive experience with pyrotechnics, he mentions the effects of the saltpeter, of the sulfur, of the charcoal, of the iron sand, etc., and the fact that obstructions in the choke cause the piece to shake or to jump about

34–37 The coated and composite grains evidently represent a technique of Chinese origin and indicate that certain of the effects of the fireworks are intended to be observed in the daytime The burning grains of powder trace out their flight both by their flame and by their smoke A compact mass or grain of burning composition, thrown out from a rocket, Roman candle, gerb, fountain, or flower pot, is called a *star* in our present practice. Composite stars are made in this country in such manner that the stars change color while they are burning or that the single stars burst into several stars of the same or of different colors But daylight fireworks have not been popular, and we have not known of stars being coated with materials which produce colored smokes as is described in the Chinese text The use of iron sand would produce an effect similar to that of penny sparklers or of electric spreader stars.

38. It is a good practical observation that the powder for crackers must be packed loosely but that the powder for fountains is pressed hard. The hard-pressed mixture burns from its surface, the flame from the burning cannot penetrate into its mass If it were loosely packed, like granular gunpowder, the mixture would burn rapidly throughout its mass and an explosion would result The tendency of mixtures containing iron sand to lose their uniformity is also correctly noted. These mixtures must be stirred constantly while they are being loaded and then pressed, tamped, or pounded so firmly into place that they can no longer separate

39. The Chinese names for the various pieces of fireworks are no more bizarre and fantastic than those which are used in this country Recent American catalogues list such pieces as "jeweled cascade," "devil among the tailors," "golden sunrise," "whistling pigeon," "wheel of fortune," "illuminated surprise," "yellowstone wonders," "fountain of youth," "jack in the box," "horn of plenty," "diamond necklace," "Hawaiian frolic," "dance of the fairies," and "messenger to Mars"

42. The fireproofing of paper with alum, or, if this is insufficient, by the use of an additional dusting with zinc carbonate, fuller's earth, or lime

54 Sympathetic magic. the bad effects upon the powder of mourning, death, funerals, etc , but, if the mourning is for someone outside of the immediate family, then its effect may be counteracted by magical means.

55. Magical effects on the powder of the beating of a drum Wood ashes mixed into the powder make it burn more slowly

56. An intermingling here of magic with sound good sense. several sage precautions to be observed in the handling or powder are mentioned The statement that the powder takes fire spontaneously after long standing in the wind appears to be in error, but may perhaps contain a certain element of truth. The several components of the powder, differing in density, would be more or less separated by the wind, and the blowing about and settling of the dust would introduce new hazards which might result in easy, if not actually spontaneous, ignition

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NEW RESEARCHES ON MAGNETIZATION BY ROTATION AND THE GYROMAGNETIC RATIOS OF FERROMAGNETIC SUBSTANCES

By S. J. Barnett

NEW RESEARCHES ON MAGNETIZATION BY ROTATION AND THE GYROMAGNETIC RATIOS OF FERROMAGNETIC SUBSTANCES

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1. Introduction. Since 1914, when the first gyromagnetic effect to be observed was discovered,[1] by a method of electromagnetic induction, many researches have been made on the gyromagnetic ratios of magnetic substances. In the case of ferromagnetic substances, successful measurements of this ratio (i e. the ratio of the angular momentum of the magnetic element to its magnetic moment) have been made by investigating two different, but closely related effects, viz: (1) *magnetization by rotation*, or the *Barnett effect;* and (2) *rotation by magnetization*, or the *Einstein-de Haas effect.*

Much the most extensive measurements have been made in my own laboratories, in two series, as follows: one series (I) by means of my own effect (1920–1925),[2, 3] the other series (II) by means of the Einstein-de Haas effect (1925–1939).[3] The results of the two investigations agree, for the most part, very well, but those of the second are much the more precise, partly because the sources of error in working with the Einstein-de Haas effect, while themselves quite difficult to eliminate thoroughly, are not so difficult to eliminate as are those encountered in working with the other effect. The evidence appears to show definitely that the results of Series II are the most precise which have hitherto been obtained.

On account of such discrepancies as exist between the results of Series I and Series II it has long seemed important to make a new and independent investigation of the rotors used in Series I by means of the same effect, even if increased precision should be impracticable to attain. The first part of such an investigation is described in this paper. Fortunately, for most of the rotors, the precision has already been considerably increased over that of Series I.

At the same time it is important to study the various methods of investigation further with the hope of increasing the precision. For the pure magnetic metals and alloys to which my own work has been restricted, the values of the gyromagnetic ratio extend through only the small range from about $m/e \times 1.00$ to about $m/e \times 1.08$ or 1.09, and only two of them are known to less than one per cent. Furthermore, as Professor Pierre Weiss remarked to me at the Strasbourg *Réunion*,[3] the work "must be extended to more

[1] Ohio Academy of Sciences and American Physical Society, November and December, 1914. See S. J. Barnett, *Magnetization by rotation*, Phys. Review 6: 239–270, 1915.

[2] S. J and L. J H Barnett, Proc Amer Acad. 60. 127–216, 1925.

[3] See especially S J. Barnett, *Gyromagnetic ratios for ferromagnetic substances New determinations and a new discussion of earlier determinations.* Proc. Amer. Acad. 73, 401–455, 1940. See also a briefer discussion in the reports of the *Reunion d'Études sur le Magnetisme*, held at Strasbourg under the presidency of P. Weiss in 1939. These reports were published in Paris by the *Institut International de Cooperation Intellectuelle* and the *Service Central de la Récherche*

substances and to the same substances in different states, and for this purpose it is necessary to increase the precision."

Series I was made by a magnetometer method in a building free from iron, a part of the plant of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, where the magnetometer could be controlled without too great difficulty. Experience in the Norman Bridge Laboratory, which is full of iron, involving the use of a magnetometer in another investigation,[4] convinced me that in this laboratory the method of electromagnetic induction would be preferable, if it could be made sufficiently sensitive, on account of the superior degree of freedom from asymmetry—the source of most of the errors—which it makes possible. At the same time it offers the great advantage over the magnetometer method that in it provision can far more readily be made to measure only changes of magnetization instead of magnetization itself. Furthermore, for the sake of a greater degree of independence, it was desirable to adopt a method radically different from that used in Washington.

The new work is still far from complete, progress having been greatly interfered with by the defense and war situations. While it is certain that the work can be greatly improved in many particulars, nevertheless a degree of precision at first hardly hoped for by the method of investigation here adopted has already been achieved in this preliminary work, and important independent confirmations of earlier work obtained. For this reason, and because the investigation cannot probably be greatly advanced until after the war is over, publication of the work already accomplished is being made at this time.

2. Principal sources of error associated with the rotation in the method of electromagnetic induction Most of the sources of error so far discovered in the study of magnetization by rotation, together with methods designed to eliminate them, are discussed in the earlier papers. Some of these will be treated further, and others will be discussed, in this paper. The sources of error directly associated with the rotation may be divided into two classes as follows:

A. *Sources independent of the rotor's magnetization*, viz.. (1) eddy currents arising from incomplete compensation of the earth's magnetic field, (2) electric currents produced by thermal effects at the bearings and by air driven by the moving rotor against the adjacent parts of the apparatus, (3) electrical or magnetic effects in the motor and other driving apparatus and auxiliary apparatus.

B. *Sources dependent on the rotor's magnetization*, viz.: (1) torsion of the rotor, driven from one end and moving with friction in a bearing at the other, (2) thermal effects on the rotor due to friction at the bearings and to air currents, (3) centrifugal expansion, and other strains, produced by the rotation and perhaps by gravitation, (4) axial displacement of the rotor produced by the rotation, (5) displacement of the rotor in altitude or azimuth, or distortion, in the incompletely compensated magnetic field of the earth, (6) non-uniform initial position-angle setting of the rotor, (7) vibration.

3 The method of electromagnetic induction as applied to the study of magnetization by rotation. In the method of electromagnetic induction a coaxial coil of insulated wire surrounds the rod under investigation and is connected in circuit with a galvanometer of the fluxmeter type. If the magnetic moment of the rotor is changed by any small amount the fluxmeter gives a deflection proportional thereto. In the main experiment the angular velocity of the rotor is changed by the amount $\delta\Omega$ and a change of magnetic moment δM results, producing a deflection D of the fluxmeter. In a calibrating experiment a minute axial magnetic intensity is applied to the rotor and is altered by an amount δH. This produces a change $\delta M'$ in the moment, which causes a deflection Δ of the fluxmeter. The quantities δM and $\delta M'$ are proportional, respectively, to the change $\rho\delta\Omega$ (where ρ is the gyromagnetic ratio of the magnetic element) in the intrinsic magnetic intensity of rotation and the change δH in the intensity of the axial field. Thus we have

$$\frac{\delta M}{\delta M'} = \frac{\rho\delta\Omega}{\delta H} = \frac{D}{\Delta}$$

whence

$$\rho = \frac{D}{\Delta} \cdot \frac{\delta H}{\rho\Omega} \quad . \quad . \quad . \quad . \quad (3\text{—}1)$$

In the actual earlier experiments by this method *two similar* rods were mounted with their axes horizontal and normal to the magnetic meridian, and *two similar* coils of insulated copper

Scientifique de France, under whose auspices the *Réunion* was held, but their general distribution has hitherto been prevented by the war

[4] Proc. Amer. Acad. 68: 229, 1933.

wire were mounted symmetrically about their centers, as shown in Fig. 3—1. These coils were placed in series with one another and with the fluxmeter and were oppositely connected so that any fluctuations in the intensity of the earth's magnetic field, which act in the same way on both rods, might produce no effect on the fluxmeter. One of the rods, the *compensator*, *A*, remained at rest; while the other, the *rotor*, *B*, was alternately rotated in opposite directions, the change in its magnetization being determined as it came to rest or to very low speed. For use in the standardizing experiments the rods *A* and *B* were uniformly wound with single layer coils of insulated copper wire; and two long wooden rods

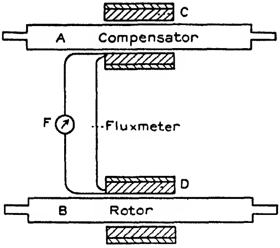

FIGURE 3-1.

of the same diameter and similarly wound were provided for attachment to the ends of the rotor, in order to make reductions to a strictly uniform field. The earth's field, in the region occupied by the rotor, was, in general, neutralized in order to prevent eddy currents and changes in its axial flux due to alterations in the shape or position of the rod, including possible slight alterations of axial orientation caused by the rotation. In alternate runs the rotor was rotated in opposite directions at the same speed in order to eliminate the effects of changes of magnetization due to centrifugal expansion and other disturbing effects. To eliminate the effects of torsion, observations were made for the two orientations of the rotor's axis, 180° apart. The mean result is free from torsional error if the frictional torques at the two ends of the rotor are exactly identical. Unless the bearings and journals at the two ends are exactly similar, complete elimination of the error would necessitate that the bearings also be reversed—a precaution not taken in any of the work, and if the centrifugal thrusts on the bearings due to axial asymmetry of the rotor are different at the two ends, complete elimination of the error would necessitate also that the rotor be driven alternately from the two ends, instead of only from one end, with a single motor. This precaution has been taken only in a part of the new work. Such interchange of motors may help, furthermore, to eliminate the possible error due to differential longitudinal shift of a rotor on reversal of its direction of rotation.

4. MECHANICAL ARRANGEMENTS IN THE NEW WORK WITH ROTOR AXIS HORIZONTAL AND ROTOR AXIS VERTICAL. In the greater part of the new work the rotor, compensator, etc were mounted with axes horizontal, as in all the work done hitherto. In the remainder of the work the axis of rotation was vertical

In all the earlier work the rotor was always directly driven by a single countershaft, or a series of countershafts, permanently located either east or west of it To eliminate certain errors, especially that due to torsion, it was therefore necessary to reverse the rotor's azimuth periodically—a not very troublesome operation, but one requiring time and introducing some uncertainty because of the possible changes in the rotor's magnetization incurred in the process.

Primarily in order to effect the same elimination, in that part of the present work in which the rotor was mounted with the axis horizontal, it was located symmetrically between two exactly similar motors at equal distances, and was driven at will by either one through a series of four countershafts The motors are of the synchronous type and were always driven at the same speed, viz 60 r. p s. In general equal numbers of observations were made with the two motors

The countershafts were simple bakelite tubes of various sorts, with internal diameter one-half inch and walls one-sixteenth, three thirty-seconds and one-eighth inch thick. They ranged in length from about one foot to about two feet. Each of the tubes nearest the rotor was provided with a brass terminal piece centrally drilled to fit the rotor journals It was attached to the tube by two similar screws at opposite ends of a diameter, and to the rotor by a set-screw and nut, with a counterbalance on the other side. The

terminal pieces used in much of the work ended in circular flanges which were drilled with sixteen holes uniformly spaced around the edge, to serve as position angle indicators. The other end of

FIGURE 4-1 When this photograph was taken the west motor etc had been removed to make room for the vertical drips arrangements, which are shown in place on the left

the tube, in the earlier part of the work, slipped over a half-inch journal, to which it was fastened with small screws when in operation.

This journal was part of a bronze thrust bearing permitting only very slight longitudinal motion When the screws were removed, the tube could be slipped farther on to the journal, freeing the rotor entirely from the tube In later work, in order to reduce longitudinal play still further, each of these cylindrical thrust bearings was replaced by a combination ball and cylinder bearing. Only one of these ball and cylinder bearings was used with vertical drive. The cylinder was of bronze. The balls and rings were of steel, but were too small (and too well demagnetized) to have any appreciable effect on the work. The other journals of the countershaft system were of bronze or stainless steel, one-half inch in diameter, and ran in bearings of babbitt metal in bronze blocks. All the bearing blocks were mounted either on the bed plate carrying the rotor, on on separate piers of concrete made from white limestone and white Atlas cement

For horizontal drive, the motors were mounted on separate concrete piers and drove the countershafts directly at 60 r. p. s. The rotor was halfway between the motors, which were nearly nineteen feet apart.

The bakelite tubes are insulators so that no eddy currents were formed in them; also no currents of thermal origin could traverse them. Their lack of great torsional stiffness helped to prevent too great initial acceleration of the rotor, and their flexibility made it unnecessary to take the greatest pains to secure exact alignment. They are also so light that mechanical disturbances when they do not run true are at a minimum.

While the Washington work (I) was in progress, Mr. C. A. Kotterman, now of the Bell Telephone Laboratories, who acted as research assistant, suggested that in order to eliminate friction at the end of the rotor more remote from the motor we use vertical drive instead of horizontal drive. The effect of the torsion produced by this friction was small, however, and was eliminated without great difficulty. At the same time the change to vertical drive would have required a great deal of labor and expense. Hence the change was not made. In the course of the new experiments with horizontal drive, however, it appeared that some of the disturbances might be due to flexure of the rotor by the earth's gravitational field; and in order to avoid this and at the same time reduce torsion it was concluded to adopt Mr. Kotterman's suggestion and modify the apparatus to make vertical drive possible. In the arrangement adopted the rotor was driven from above

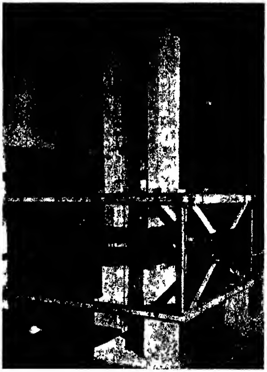

FIGURE 4-2

only by a single motor, so that the possible torsional effect due to centrifugal thrust of the lower journal against its bearing was not eliminated.

In all the new work the rotors were mounted on the small bed-plate used before, and in bearings which are similar except that bearing bronze is substituted for the agate mostly used before. In a good deal of the work the small cylinders acting as bearing pieces have been slotted, and the clearance between journal and bearing piece adjusted when desirable by means of screws set into the heads of the bed-plate and acting radially at both sides of the slot.

formed. Material was lacking to make the magnetic part of this rotor as long as that of the others, and the defect was made up by extending the length of the bronze journal pieces. The diameter is 3 0 cm. and the length of the magnetic material 20 5 cm.

Another new rotor is Electrolytic Iron III. It was cut from a new rod of Dr. Yensen's electrolytic iron, and is 3 0 cm. in diameter.

A third new rotor is Nickel IV, cut from a rod obtained from the International Nickel Co

Finally, the old rotor Cobalt I, used in Columbus and Washington, was provided with terminals similar to those on the other rotors The

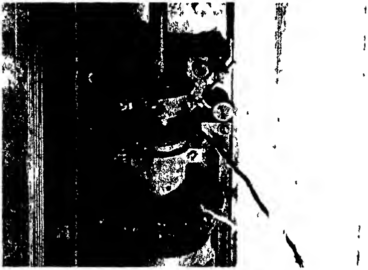

FIGURE 4–3.

later and better type of construction used in Washington was adopted.

In the work with axis horizontal the small rotor bed-plate was mounted on the same heavy bronze bed-plate used for this purpose in Washington; while in the work with axis vertical the rotor bed-plate, the motor and all the extra bearings were mounted on a new long and heavy combination brass-and-bronze bed-plate bolted to a heavy vertical concrete pier resting on the floor, and to a heavy steel beam in the ceiling of the laboratory. See Figs. 4—1 and 4—2.

In Fig. 4—3 the test coil, heavily insulated with felt, is shown mounted in position for vertical drive.

5. THE ROTORS. Most of the rotors are the rotors used in Washington. Three new rotors have been constructed, and one rotor used earlier reconstructed. One of the new rotors is Electrolytic Iron IV. This is from a part of the same rod of iron from which Electrolytic Iron II was

6. MOTORS, SPEEDS, AND CORRECTION FOR IMPERFECT FLUXMETER ACTION In the earlier work the accurate determination of speeds and the requirement of strictly identical speeds for the two directions of rotation, or of correction for the difference, made a great deal of labor necessary All this vanished in the new work because alternating current power with the constant and precise frequency 60 cycles per second was always available, and synchronous motors could be used to obtain exactly 60 revolutions per second. Additional speeds were not used.

The motors are 1/8 h. p, self-starting synchronous motors by the General Electric Company. When the unmodified motor is used to drive the equipment, full speed is attained in about 0 5 or 0 6 second after the circuit is closed.

It is highly desirable that this starting interval be as short as possible in order that the galvanometer readings may be interpreted correctly. Nevertheless, when the observations began, it was feared that the acceleration corresponding to the time mentioned would be too great, perhaps for both magnetic and mechanical reasons. Hence an inertia wheel was constructed, in three parts. The first, A, is a heavy rolled brass disk provided with an axle and set-screw for attachment to the motor like a pulley. The second, B, is a ring of the same material which can be screwed onto one side of the first; and the third, C, a similar ring which can be screwed onto the other side of the first. The rings fit accurately over short hubs turned on the two sides of A, so that balancing is automatically secured

The times required to attain full speed with one, two, and three discs, respectively, were approximately 1 1 second, 1 8 seconds, and 2.8 seconds.

While a number of observations were made with one and two discs loading the motors, it was found that all the discs could be discarded, and in most of the work they were not used at all

It was at first supposed that a correction to the galvanometer readings might be necessary because the fluxmeter action is not perfect and the different effects which act on the secondary circuit, and which the galvanometers integrate, are not completed in the same time Special time-lag experiments, however, have shown that no correction is necessary except when as many as two discs load the motor It was estimated that in this case a (negative) correction of about one-fourth per cent should be made to the apparent values of ρ, and this correction has been applied to the relatively few results obtained with two discs.

7. Neutralization of the earth's magnetic field If the rotor were strictly cylindrical and homogeneous, and if the surrounding secondary coil were truly cylindrical and regularly wound with its wires truly circular, and were mounted coaxial and otherwise symmetrical about the rotor, then eddy currents due to the rotation of the rotor in the earth's field would produce no resultant flux through the secondary coil, and it would thus be unnecessary (on this account) to annul the field Partly because these conditions were not completely realized, the chief experiments were made with the earth's mean intensity in the region occupied by the rotor annulled as far as was practicable.

An additional reason for annulling the earth's field is to prevent any change of flux through the rotor due either to a minute change in its altitude or azimuth made possible by the existence of a small amount of bearing clearance, to flexure produced by gravitation or centrifugal action, or to lack of magnetic symmetry.

In the earlier part of the work with axis horizontal, the earth's magnetic field was annulled by two sets of coils of insulated copper wire. The principal set consisted of two pairs of long rectangular coils mounted with their wires (except for the ends of one coil pair) horizontal and symmetrical about the rotor, and thus normal to the magnetic meridian. The coils

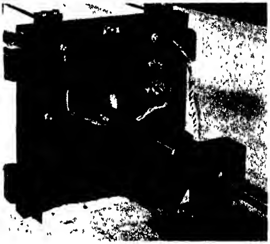

Figure 7-1.

were all somewhat more than 2 1 m long, and all were about 25.5 cm wide (See Figs. 4—1 and 7—1). The mean planes of the coils which annulled the vertical component of the earth's intensity were about 16 cm. apart, and those of the coil which annulled the horizontal component about 17 cm. apart They were wound in grooves 1/16 inch apart (center to center), cut accurately in square bakelite blocks 25 5 cm on each side and 2.5 cm. thick. Each coil was kept stretched tight by means of two springs whose tension could be adjusted as shown in Fig. 4—1. The coil pair which annulled the vertical intensity had 26 turns, the other 12 turns. The other set of coils consisted of the large square Helmholtz pair used in the work on the Einstein-de Haas effect, which hung nearby. This coil-pair was connected in parallel with the other vertical-intensity rectangular coil and, as it happened,

made the residual field at the rotor more nearly uniform than it would have been without it.

In the later part of the work with axis horizontal, the large Helmholtz pair was disconnected and the copper wires of the other coils were replaced by No. 20 bare spring brass wires. In each coil the spacing of the grooves prevented the individual wires from touching their neighbors. Vibration of the wires was prevented by the application of small pieces of surgeon's tape.

When the apparatus was mounted with axis vertical, three coils were used to neutralize the earth's magnetic field See Fig 4—2. The vertical intensity coil was the coil used for the same purpose in the Einstein-de Haas investigation, which was moved from its old position and mounted symmetrically about the center of the rotor. It was held in position by vertical brass wires attached to the ceiling and horizontal wooden rods connected with the pier The N-S and E-W components of the horizontal intensity were neutralized by two long coils constructed much like those used in the latter part of the work with axis horizontal The E-W coil had only two turns in each half; the N-S coil had eight The bakelite end pieces were securely fastened to the concrete above and below by pieces of brass and bronze, and the wires were held taut by set screws, working in bakelite, which pressed against the upper ends of the loops. By means of the compensating coils the earth's mean intensity in the region occupied by the rotor was reduced to a small fraction of one per cent

8 TEST, COMPENSATING, AND CALIBRATING COILS. In the work with axis horizontal two pairs of test coils were used, of nearly the same dimensions and with nearly the same numbers of turns They were mounted as in Fig. 3—1 One pair was wound on bakelite bobbins, the other on brass bobbins. The coils of the first pair were machine wound by the Inca Co., but the windings were not very regular The coils of the second pair were wound with great regularity by the Hollywood Transformer Co., and were used in the greater part of the work. These coils were six inches long, ½ inch thick, and had internal diameters of 1⅞ inches. Each contained a little more than 14,000 turns of No. 28 enameled copper wire. One coil served as rotor or test coil, and the other as compensator coil.

Three almost exactly similar calibrating coils were wound, one on a bakelite tube, the others on brass tubes. In the case of the last two coils great care was taken to see that the insulation was always perfect (except at one end, where the wire was usually attached to the tube). The first coil was used chiefly in the earlier part of the work. For details of the windings see § 17.

The test coil was mounted with precision, in brass clamps, coaxial with the rotor on the small bed-plate, and the calibrating coil was mounted coaxial inside the bobbin of the test coil. The centers of both coils and the rotor were practically coincident.

In the work with axis vertical, after a few observations made with one of the Hollywood coils as compensator, mounted on the laboratory wall, it was replaced by a large Helmholtz pair centered on the rotor See Figs 4—2 and 8—1.

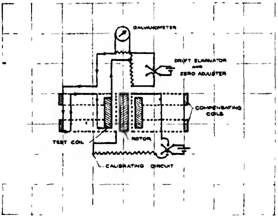

FIGURE 8-1

Each coil of the pair was nearly square, about 2 ft. on the side, 4 in. wide, and 1 in thick. The complete coil was wound with 2000 turns of No 20 insulated copper wire in sections—each divided equally between the two halves, except for a few turns, permitting any even number of turns to be used from 2 to 2000. A special switchboard was provided for making the connections The coil and board were electrically screened and thermally insulated with felt.

In addition to the great advantage of having the compensating coil centered on the rotor and its coil, there are the additional advantages of low resistance and of being able to determine with ease the proper number of turns for exact compensation for each rotor

An approximate determination can be made by adjusting the current in the vertical earth intensity coil until the vertical intensity is annulled, then adjusting the number of turns until,

with the secondary circuit closed through a galvanometer, no deflection occurs when a slight change is made in the current of the vertical intensity coil.

If the field of the vertical intensity coil were uniform throughout the extent of the compensating coil, this determination would be exact. The correction which must be applied to make it exact was readily found by subsidiary experiments made with the help of additional coils of the proper shapes but smaller dimensions. It was found that the number of turns determined as above must be multiplied by 1.007.

It was found necessary to screen electrically the whole secondary circuit. Much of it was insulated thermally.

9. THE GALVANOMETERS, PHOTOELECTRIC CELLS, ETC. In order to attain adequate sensitivity, two galvanometers were used in conjunction with either two similar photoelectric cells or a Moll thermo-relay, which was used in a relatively small part of the work.* The first galvanometer had the characteristics of a fluxmeter. The optical arrangements finally adopted were as follows (See Fig. 9—1)·

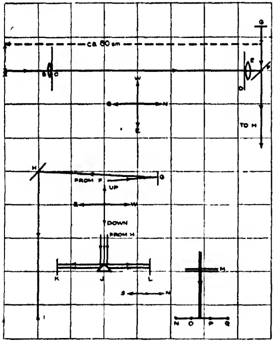

FIGURE 9–1.

* I am indebted to Dr. Yensen and Dr. Goetz for information with regard to the photoelectric cells, and to the latter for the loan of the Moll relay.

A beam of light from the filament A of an electric lamp passed in a horizontal plane from S. to N through a short-focus convex lens B and a rectangular opening C in a thin brass plate in contact therewith, and onward through a circular opening D and a long-focus convex lens E to a plane mirror F. This mirror sent the beam westward and slightly upward until it fell on the plane mirror G of the galvanometer in circuit with the rotor and compensator coils. An image of a part of the filament was formed on the mirror G. From this mirror the beam was reflected eastward and slightly upward. It fell on a plane mirror H, which reflected it vertically downward. An image of the rectangular opening C was formed in a fixed position I if there was no current through the galvanometer and if no further provisions were made.

When the photoelectric cells were used (Fig. 9—1) the beam was divided into two equal parts by reflection from a right angled prism J. An image of half of the opening C was formed on the face of each of the cells, K and L. When the galvanometer mirror moved, the upper edge of each half image remained essentially fixed while the two lower edges moved in opposite directions equally. When the Moll relay was used the vertical beam passed through a cylindrical lens M, which concentrated the light from C, made narrow for this purpose, on or near the center of the thermocouple $NOPQ$.

With a galvanometer having the characteristics of a fluxmeter there is of course, in general, a more or less slow drift, which it is often necessary to compensate. This was accomplished, when necessary, as in the work of 1914 and 1915, by introducing a minute extraneous electromotive force into the circuit. A single dry cell was connected through a reversing switch to the terminals of the high resistance of an Ayrton shunt. Leads were connected from the variable resistance terminals through an adjustable resistance box to two points, with a very low resistance between them, in the galvanometer circuit. This arrangement not only serves to eliminate the drift but provides a useful device to control the galvanometer while making adjustments.

The mirrors F and H and the lenses E and M were provided with all necessary adjustments; and the prism J, or the Moll relay NQ, was mounted on a small table which could be moved northward or southward by means of a fine micrometer screw.

When the photoelectric cells were used, they

were connected in opposition to one another, and either in series or in parallel, in closed circuit with the second galvanometer, suitably shunted to produce critical or approximately critical damping. When the Moll relay was used its terminals NQ were connected to the galvanometer terminals through a series resistance sufficient to produce critical damping.

The galvanometers with their support and all the optical devices, except A, B, and C were mounted inside a box of wood internally blackened and sufficiently tight to prevent trouble from convection currents. Internal blackened screens were also provided to prevent extraneous light from reaching the photoelectric cells and to limit the beam where necessary. The lens B and the brass plate with opening C were mounted at the end of a large bakelite tube supported on a concrete block and projecting through a wall of the box without contact. The opening between the two was screened with black cloth. The lamp A was mounted on a separate concrete pier

10. THE GALVANOMETER SUPPORT. Since the angular motion of the beam of light after reflection from the mirror of galvanometer G is very minute, it was imperative that the galvanometer be mounted on a support as free from vibration as possible. Four thin brass rods were mounted vertical, or nearly vertical, in four brass castings resting firmly on a heavy concrete shelf. A horizontal rectangular wooden board was fastened to the tops of these rods near its corners From points of this board, also near the corners, but nearer to the center than the rods, four vertical brass tubes proceeded downward At the bottom, a little above the stone shelf, they carried a second board similar to the first; and at a level about three quarters of the distance from the top to the bottom they carried a third and heavier board. Across the central part of the top of this was screwed a still heavier board on which both galvanometers were mounted. A number of pieces of angle iron were screwed to the boards to prevent their warping. The lower board carried heavy weights, and on top of the upper board were pans of oil to provide internal damping. The masses were all arranged as symmetrically as practicable about a vertical line through the center. The arrangement formed a heavily damped inverted pendulum, and behaved much like the apparatus devised for the same purpose by R. Müller. In Müller's apparatus, however, there were only three rods, instead of four, so that horizontal motions are much more likely to produce angular motion of the suspended system.

11. ELIMINATION OF EDDY CURRENT EFFECTS. Tests for eddy current effects were made in several different ways, as follows:

I. As in the Washington investigation, numerous measurements were made with a copper rotor[5] of nearly the same dimensions as the larger magnetic rotors, similarly placed and rotating both in the earth's unaltered field and in the compensated fields with the same speed of 60 r. p. s. The first experiments were made with the Inca coils in use. In the uncompensated field reversal of rotation gave a mean deflection of + 4.44 cm. when the coil was so set that a mark on its bobbin was as far south as possible. When the coil was set with the mark north, the corresponding deflection was − 1.09 cm. When the field was compensated the corresponding deflections were + 0 86 cm. and + 0.10 cm. The sensitivity was such that the same reversal of rotation of the permalloy rotor would have given the deflection − 15 cm. Thus with the mean field annulled and the coil set at the position angle giving the less effect, the apparent eddy current effect in copper was about 1 part in 150 of the gyromagnetic effect in permalloy and in the opposite direction, indicating that the *apparent* gyromagnetic ratio should be slightly increased. As shown in earlier papers, however, the eddy current effect in the magnetic rotors should be much less than that in copper, and thus much less than 1 part in 150 in the case of the permalloy rotor, with the coil set as above.

In the case of the Hollywood Transformer Company's coils with axis horizontal, the mean eddy current deflection for copper in the compensated field was less than + 0.1 mm. when the sensitivity was such that the gyromagnetic effect in Cobalt II was about + 6.3 cm. The deflection was practically independent of the position angle of the coil (over a range of 270°). When the apparatus was mounted with axis vertical, the copper deflection was − 0 003 cm. when the gyromagnetic deflection for the rotor Fe IV was about − 4.5 cm.

II. Direct experiments on the eddy current effects in the full uncompensated field of the earth were made on two of the magnetic rotors,

[5] The copper rotor had journals which were not insulated from the main body of the rotor. Hence it is possible that a part of the copper effect may originate from thermal e. m. f. s at the (bronze) bearings.

viz., Permalloy and Norway Iron The Permalloy was rotated both in the neutral field, in the original uncompensated field, and in the original field approximately reversed The Norway iron was rotated in the original field and in the original field reversed. The experiments showed that the *full original* field *reduced* the apparent gyromagnetic ratios by the fraction 0.025 ± 0.005.

III. In a few of the gyromagnetic experiments made with the Inca coils, the rotor coil was mounted with the mark in one of its two positions only In most of the work with these coils, however, observations in nearly equal numbers were taken with the coil set at this position angle and the angle differing from this by 180° In one case the eddy current effect, if any, should be many times greater than in the other For the seven rotors investigated in this group (Group I) the difference between the apparent values of ρ for the two cases was only the fraction 0.003 ± 0.012 of ρ, the average error being thus four times as great as the apparent difference between the two eddy current effects No correction, was made to the results obtained in either way

IV. In most of the horizontal drive experiments made with the Hollywood coils, still another test was applied. Half the rotations were made with a mark on one end of the bobbin east, and half with the coil reversed in azimuth and the mark west The mean difference found for $\rho_E - \rho_W$ was -0.002 ± 0.015

12. THE POSITION ANGLE ERROR AND ITS ELIMINATION. If the coil, the rotor, and its magnetization possessed perfect axial symmetry, and the various effects above considered vanished, no change of flux through the secondary circuit would occur when the rotor is turned from one position angle to another On account of asymmetry, however, such changes usually occur If the rotor is set at a given position angle and then driven up to full speed (or any but a very small speed) the galvanometer gives a deflection P corresponding to the change of flux from its initial value to its mean value; and this effect is added to all the other effects involved Since it is independent of the direction of rotation it is eliminated from the final result if the rotor is set initially at the same position angle for both directions of rotation. The deflection P retains very nearly the same magnitude, but changes its sign, when the initial position angle is altered by 180°. To make the elimination more certainly complete, each group of observations mark U (or W) and mark D (or E) in the standard sets was made in two parts, (1) and (2), the initial position angles in the two differing by 180°. Also, the initial position angles were in general, but not always, so chosen that the deflection P was a small part of the gyromagnetic deflection R. In some cases P/R was greater than unity.

The effect under discussion was usually investigated for the various rotors by observations independent of the main rotation experiments. In the method frequently employed the rotor was repeatedly set initially at a given position angle, and then turned suddenly in separate experiments from this initial angle to each of a series of angles differing from this by intervals up to nearly 360°. A rough curve was platted between the deflection and the increment of the position angle.

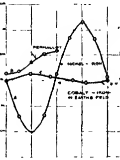

FIGURE 12-1

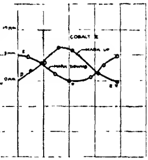

FIGURE 12-2.

In the main experiments the rotor was then set at the position angles corresponding to the mean deflection. This makes P zero or a minimum

Curves of this sort are given for several rotors in Fig. 12—1 and Fig. 12—2 All the curves are for axis horizontal except that for Cobalt-Iron, which was mounted with axis vertical The curve shown for this rotor was obtained when only the vertical component of the earth's magnetic intensity was annulled. This rotor, and some of the others, gave effects too small to measure readily when mounted with axes vertical in a completely neutral field.

13 EFFECTS OF MOTORS AND BEARINGS. Inasmuch as the motors and ball bearings are made of iron they doubtless alter slightly the magnetic intensity of the field acting on the rotor and its coil. There was no reason, however, to expect the rotation of motor and bearing parts to produce any mean effect; and especially there was no reason to expect the *reversal* of their rotations to produce any effect.

Furthermore, direct experiments made with the rotor and compensator at rest and in their

standard positions, but with the motor and all the other driving mechanism in rotation except the countershaft nearest the rotor, have shown that these rotating parts produce no certain effect. No effect of the countershafts nearest the rotor was to be feared because they are made of bakelite tubes with only small brass plugs at the ends nearest the rotor. Thus with the Cobalt-Iron rotor in position and at rest, reversal of the motor etc gave the mean deflection -0.015 ± 0.011 cm. with sensitivity such that a deflection of -8 cm. would have been produced by a corresponding reversal of the rotor's own rotation

14. Effects of radial forces on rotors Rough tests were made on several of the rotors set at fixed position angles, to see what would happen in both compensated and uncompensated fields when either end of the rotor was pushed strongly by hand (at a point just outside the bearing) northward and southward, or upward and downward. In one case the middle of the rotor also was pushed. For Cobalt II and Electrolytic Iron IV, which showed very large effects of longitudinal motion, the deflections were only small fractions of the gyromagnetic deflections, likewise for Cobalt I. For Nickel I the deflections were of the same order as the gyromagnetic deflection, but in most cases smaller. For Nickel IV the effects were large, some of them much larger than the gyromagnetic deflection. The effects vary in sign and magnitude with the orientation of the axis of the rotor, with the position angle, with the direction of push, and with the magnetic field, and undoubtedly with other factors, and in such a complicated way as to defy a satisfactory analysis at the present time.

If such effects are produced in the principal experiments on account of asymmetry, by the rotation of the rotor, as they doubtless are, they can have only a small effect on the determination of the gyromagnetic ratios, because they must be nearly identical for both directions of rotation The only reason they may not be exactly identical is that the rotor journals must move laterally to slightly different positions for the two directions of rotation.

These effects doubtless enter into the quantity designated below as M_r which is calculated on the assumption that it is proportional to an even power of the speed, and so independent of the direction of rotation.

If any part of the effect is proportional to the speed, it is probably partly eliminated as the torsion effect is eliminated by reversing the rotor in its bearings and by reversing the drive from one end to the other. The effects usually reversed in this manner and designated below by T cannot be due entirely to torsion, because they are in at least some cases largely independent of the rotor's residual magnetic moment, in both sign and magnitude.

15. Errors due to axial shift of the rotors. When a rotor is driven either right-handed or left-handed, it is possible for several reasons that a longitudinal shift R or L may occur; and the shift may be different for the two directions of rotation If R-L is not zero a systematic error may thus be introduced

On this account three series of measurements of longitudinal displacements were made. The first series was made with a telescope and scale while the cylindrical bearings were in use (Group I) With the right motor in operation, no differential effect was observed; with the left motor, a displacement of possibly 1/20 mm. at first occurred This disappeared, however, when the bearings were oiled, as they were oiled in the gyromagnetic experiments proper. In this case R and L were both zero, and it was estimated that a shift of 1/100 mm would have been detected.

The second series was made with a microscope after the ball bearings had been installed for horizontal drive (Group II). Probably 0 003 mm. would have been observed, but no shift was detectable. Only one of the two similar sets of bearings was investigated

The third series was made after the apparatus had been mounted for vertical drive (Group III), with a long range microscope especially constructed for the purpose Several rotors were used. For Electrolytic Iron III, Permalloy, and Steel IV (a small rotor) the mean measured shifts (R-L) were $+0.002$ mm., $+0.002$ mm. (and again -0.001 mm), and -0.002 mm., respectively

Supplementing these measurements, many others were made on the galvanometer deflections produced by moving the rotors longitudinally in their bearings through measured distances of a few millimeters. In each case the mean deflection D produced by moving the rotor eastward (or downward in the case of vertical drive) through a distance of 1/100 mm. was calculated, together with the ratio of D to the gyromagnetic deflection R produced by driving the rotor up to full speed in the right-handed or

TABLE 15—1
EFFECTS OF AXIAL SHIFTS OF ROTORS

1	2	3	4	5
Rotor	Group	$I \times 10^3$	Δ	Δ'
		e m u		
Fe III	I	+0.6	+0.004	+0.004
	III	−0.2	+0.005	−0.002
		+0.2	+0.006	+0.002
Fe IV	II	−0.3	−0.024	−0.024
	III	−0.3	−0.020	−0.023
		+0.3	−0.018	−0.025
		+1.2*	−0.003	−0.003
		−1.2	−0.009	−0.009
		+1.2	−0.009	−0.006
		−0.2*	−0.002	
		+0.2	−0.002	
		+0.2	−0.003‡	
		+0.2	−0.003‡	
Steel III	III	+0.5	−0.004	−0.005
		−0.5	−0.005	−0.008
Ni I	II	−1.4	+0.005	+0.002†
	II	−0.3	+0.005†	
		+0.3	+0.007†	
	III	−0.2	+0.005	
		+0.2	0.000	

1	2	3	4	5
Rotor	Group	$I \times 10^3$	Δ	Δ'
		e. m. u		
Co II	II	+1.6	−0.012	
		+0.3	−0.008	
		−0.3	−0.012	
		+0.3	−0.009	
		+0.6	−0.010	−0.011
		−0.4	−0.016	−0.017
Hopk Al	III	−36	+0.002	+0.003‡
		+36	−0.002	
Permalloy	III	−1.8	+0.003	−0.002
		+1.8	+0.004	0.000
Cobalt Fe	III	+0.3	+0.001	0.000
		−0.3	+0.001	−0.003
Heusler Alloy	III	+0.2	+0.005†	
		−0.2	+0.005†	
Ni IV	II	+2.1	+0.038†	
	III	+0.13±*	+0.002	
		−0.13±	+0.001	
		−0.13±	0.000	+0.005
Co I	II	−1.8	−0.004	−0.004
		+1.8	−0.004	−0.004

* Demagnetized with A C

† The record does not show whether the earth's field was compensated or not.

‡ Only the vertical component of the intensity of the earth's field was annulled.

clockwise direction as seen from the west end in the case of horizontal drive (or from above in the case of vertical drive), at the same sensitivity. The mean values of this ratio, designated by Δ for the case in which the earth's field was compensated, and by Δ' for the case of uncompensated field, are given in Table 15—1.

These results, coupled with the observations on the actual longitudinal shifts of the rotors, appear to indicate that in at least most of these typical cases only negligible mean errors could have resulted from longitudinal shift. It was not practicable, however, to keep the bearings in exactly the same state at all times, so that appreciable errors doubtless sometimes occurred.

The magnitude of the quantity Δ is the fractional error in the magnitude of ρ which would result from 1/100 mm. shift.

The quantities $I \times 10^3$ in column 3 are rough values of the mean intensity of magnetization of the rotors multiplied by 1000, the sign in each case indicating the polarity of the downward (or eastward) end.

The effects Δ and Δ' would be expected to vanish if the magnetization were symmetrical about the equatorial plane of the rotor and if the longitudinal gradient of the residual magnetic intensity were zero. The parts of Δ or Δ' due to the gradient should have the same sign for all shifts in Groups I and II, and likewise for all shifts in Group III, as in fact Δ and Δ' often do. The parts due to asymmetry might or might not change sign with the measured magnitude or sign of the magnetization. Both kinds of effect are apparent in the table. A complete analysis seems impossible.

16. Processes involved in the main experiments and the standardizing experiments. In the main experiment, idealized for the case in which no sources of error are present, two processes are involved, equivalent to the following:

(1) In the first process the angular velocity of a rotor is quickly raised from O to Ω radians per second, and the galvanometer deflection R due to the change of flux $\delta\varphi_R$ through the secondary circuit is read. The change in the moment of the given rotor in this process is

$$\delta M_R = C\rho\Omega \qquad (16\text{—}1)$$

where C is a constant for the rotor. Then

$$\delta\varphi_R = {}_1K_R\delta M_R + {}_2K_R\delta M_R = K_R\delta M_R = K_RC\rho\Omega \qquad (16\text{—}2)$$

where ${}_1K_R$ and ${}_2K_R$, whose sum is K_R, are constants for the given rotor and rotor coil, and the rotor and compensating coil, respectively. Always ${}_2K_R / {}_1K_R << 1$, and ${}_2K_R$ is nearly identical for all rotors. For the deflection R produced by $\delta\varphi_R$ we have

$$R = A\delta\varphi_R = AK_RC\rho\Omega \qquad (16\text{—}3)$$

where A is constant for the secondary circuit used with the given rotor.

(2) In the second process a small current i_s is sent through the short primary coil surrounding the rotor, and the deflection S due to the change of flux $d\varphi_s$ is observed. In this case we have

$$S = A\delta\varphi_s = A\,({}_1K_s + {}_2K_s)\,\delta M_s = AK_s\delta M_s \qquad (16\text{—}4)$$

where δM_s is the change in the moment of the rotor and coil together, and ${}_1K_s$ and ${}_2K_s$, whose sum is written K_s, are constants evidently nearly equal to ${}_1K_R$ and ${}_2K_R$, but not quite equal because the equivalent intensities of magnetization are not similarly distributed in (1) and (2).

In (1) the intrinsic intensity of rotation, viz. $H_\rho \equiv \rho\Omega$, is strictly uniform, while in (2) the field acting on the rotor is not uniform, nor is the field limited to the volume occupied by the rotor. It is necessary to find the deflection Δ (§ 3) which would be produced by a known *uniform intensity* H_0 acting *on the rotor alone.*

Consider therefore the following procedure Imagine the solenoid, with diameter and number of turns per unit length unchanged, to be lengthened symmetrically about the rotor to such an extent that its field in the central section occupied by the rotor is essentially uniform, intensity $H_0 = 4\pi ni_s$. Suppose leads to be attached both at the (new) ends and at the points of the winding to which leads were attached before the length was increased.

If now the current i_s were sent through the complete coil, with the rotor in position, we should obtain, instead of (16—4)

$$S' = A\delta\varphi_s' \qquad (16\text{—}5)$$

If the same current were sent through the coil with the rotor removed we should obtain

$$S'' = A\delta\varphi_s'' \qquad (16\text{—}6)$$

Hence,

$$S' - S''\ (\equiv \Delta, \S\,3) = A\,(\delta\varphi_s' - \delta\varphi_s'') = AK_RCH_0 \qquad (16\text{—}7)$$

is the deflection produced when the intensity $H_0 = 4\pi ni_s$ acts on the rotor alone.

From (16—3) and (16—7) we find

$$\frac{\rho\Omega}{H_0} = \frac{R}{S' - S''} = \frac{R}{\Delta} \qquad (16\text{—}8)$$

It is, of course, not practicable to extend the rotor solenoid in situ as imagined above. For this and other reasons we proceed as follows:

We construct another solenoid, exactly like that imagined, and mount the rotor and the coils in the same positions with regard to it. We also replace the two galvanometer arrangement with a single galvanometer less sensitive than either of the other two, and observe the throws D_0' and D_0'' (corresponding to S' and S'') produced by reversing a current I, which is much larger than i_s but still so small that the effects produced remain proportional to currents In addition we observe the throw D_0 (corresponding to S) produced when the current I is reversed in the central part of the long solenoid (identical in dimensions etc. with the short solenoid) while the rotor is in place.

We now have

$$D_0' - D_0'' = AK_RC \cdot 4\pi nI \qquad (16\text{—}9)$$

in place of (16—7); and

$$D_0 = A\delta\varphi' = AK_s\delta M' \qquad (16\text{—}10)$$

in place of (16—4).

From (16—7) and (16—9) we get

$$\frac{S' - S''}{D_0' - D_0''} = \frac{i_s}{I} \qquad (16\text{—}11)$$

and from (16—4) and (16—10) we get

$$\frac{S}{D_0} = \frac{i_s}{I} \qquad (16\text{—}12)$$

From the last two equations we get

$$S' - S'' \equiv \Delta = (D_0' - D_0'')\frac{S}{D_0} \qquad (16\text{—}13)$$

and thus

$$\frac{\rho\Omega}{H_0} \equiv \frac{R}{\Delta} = \frac{R}{S}\left[\frac{D_0}{D_0' - D_0''}\right] = \frac{R}{S}\alpha \qquad (16\text{—}14)$$

where α is written for the quantity within the brackets.

The values of α for the different rotors used in the investigation described here are given in Table 20—1 column 12 They are known to about 0.1 per cent, and are identical for horizontal and vertical drive, and for the Inca and Hollywood coils and the two compensating coils.

From (16—14) we obtain

$$\rho = \frac{H_0}{\Omega}\ \frac{R}{S}\ \alpha \qquad (16\text{—}15)$$

In the earlier work, both that by the method of electromagnetic induction and that by the magnetometer method, the calibrating deflection corresponding to S was in general obtained for any set either before or after, or both before and after, the rotation experiments proper were completed, and with Ω either very small or zero In some cases the calibration was made with the rotor at full speed, but little difference was found.

In this work, for a greater degree of certainty, the precaution has been taken, as indicated above, to measure S and R *simultaneously* Switches are provided by which S and R can be given the same direction or opposite directions at will In half the work $S + R \equiv A$, is obtained; in the other half, $S - R \equiv B$ Then $R/S = (A - B) / (A + B)$, or

$$R = S\,(A - B) / (A + B) \qquad (16\text{—}16)$$

From (16—15) and (16—16) we get

$$\rho = \frac{H_0}{\Omega}\ \frac{(A - B)}{(A + B)}\ \alpha \qquad (16\text{—}17)$$

for the final calculation of ρ

An important reason for this procedure is that in the sensitive arrangement used in this work the sensitivity does not remain steadily constant, but often undergoes changes of a regular, or more or less irregular, character

Another important reason for this procedure is that it eliminates effects of vibration

17. The calculation of the gyromagnetic ratio. Both of the standardizing short solenoids wound on brass tubes (§ 8) had exactly the same diameters (about 41 mm. internal), lengths (about 28.5 cm), and number n of turns per cm. (44/2 540), the total number of turns in each being 494. They were lathe wound (with screw) from No. 28 cotton-enamel copper wire. The long solenoid was similar, but about 90 cm. long. Thus for each of these solenoids

$$4\pi n = \frac{4\pi \times 44}{2\,540}$$

The short solenoid wound on bakelite, through an error on the part of the mechanician who constructed it, had at first 495 turns in its complete length, but was otherwise exactly similar to those wound on brass The error was discovered, and was corrected, in the earliest part of the work, although the difference was too slight to effect the results appreciably

The standardizing current I_s was obtained from a single dry cell in series with one or more high resistance coils whose resistance Z was precisely known Usually Z was the resistance of a standard megohm box It was never less than one megohm The electromotive free ψ of the cell was determined almost every night observations were made by comparison with a standard Weston cell, itself repeatedly checked.

The angular velocity Ω in radians per second was always

$$\Omega = 2\pi \times 60$$

For e/m the value 1.759×10^7 was adopted. Thus the formula (16—15) becomes

$$\rho e/m = \frac{4\pi \times 44\,\psi\,(\text{volts})}{2.540\ \ Z\,(\text{ohms})} \times \frac{1.759 \times 10^7}{10 \times 2\pi \times 60} \times \frac{R}{S}\ \alpha \qquad (17\text{—}1)$$

When, as usually, $Z = 1$ megohm, this formula becomes

$$\rho\, e/m = 1\,0157 \times \psi \times \alpha \times R/S^{6} \qquad (17\text{—}2)$$

[6] With $Z = 1$ megohm and ψ approximately equal to 1.5 volt the quantity R/S was always less than unity. See the example in § 18. In the case of a few rotors observations with the Moll relay in use, and horizontal drive, were made both with R/S less than unity, and with R/S greater than unity, R/S in one group being approximately equal to S/R in the other. This was done in order to reduce any error which might originate in lack of proportionality between deflections

The errors in all of the constants are entirely negligible.

18. Example of a set of observations. Determination of ρ, τ, P, and M/R. The procedure in making the observations is described in the next section. An example of one set of observations (with vertical drive) is given in Table 18—2. The symbols RR, RL, etc. used in this table are interpreted in the preceding table, viz. Table 18—1. The first letter refers to the rotor, the second to the calibrating coil Thus the symbol RR means the deflection produced when the rotor, looked at from above in the case of vertical drive, or from the west end in the case of horizontal drive, is driven clockwise and the solenoid is so connected that it produces a deflection in the same direction as that produced by the gyromagnetic effect in the rotor.

The quantity R is the deflection due to the gyromagnetic effect being investigated, S the calibrating deflection, T the deflection due to the torsion (and other extraneous effects proportional to the speed and reversed with the direction of rotation), M* the deflection due to centrifugal and other mechanical effects, and P the deflection due to the fact that when the zero is read just before the motor starts the flux through the secondary circuit has not its mean value for all position angles with the rotor at rest. The subscript U or D indicates that the rotor mark is up or down (W or E for horizontal drive). All deflections are positive when directed to the observer's right.

Each set is divided into two equal parts, one with the rotor mark up, the other with the mark down. Each of these parts is divided into two subgroups, 1 and 2, for which the initial position angles of the rotor are set 180° apart (so that $P_1 = -P_2$)

We thus obtain Table 18—1, where $\overline{RR}$, $\overline{LL}$, etc. are the mean values of the deflections contained in the columns of any subgroup.

In each half set Σ_1 is the sum of all the mean deflections for the subgroup P_1, and Σ_2 the corresponding sum for the subgroup P_2

M and P have always been calculated for each half set from the formulas given in Table 18—1. The quantities $R \pm T$ and S have always been calculated for the half-groups separately, as indicated in Table 18—2, as an additional check on the work. Also, by substituting $(R+T)_U$ for R_U in the formula for ρ, ρ_u, the apparent value of ρ for mark up has been calculated, and similarly, by substituting $(R-T)_D$ for R_D' in the formula, the *apparent* value ρ_D has been calculated. The true value of ρ is $\frac{1}{2}(\rho_U + \rho_D)$. The quantity $\frac{1}{2}(\rho_U - \rho_D) = \tau$ measures the error in ρ which would have been made on account of torsion etc. except for the end-for-end reversal of

and fluxes With one rotor, Heusler Alloy, but by no means certainly for this reason, a systematic difference did appear between the results of the two groups, but there was no certain difference with the others The mean value of ρ was always taken as correct The best arrangement would doubtless have been such as always to make $R/S = 1$.

* The effects producing M, eliminated by reversal of the direction of rotation, are more complex than was supposed in the earlier work

TABLE 18—1

Interpretation of Expressions RR, RL, etc.

P	Mark Up (or W)	Mark Down (or E)
(1)	$RR = R+S+T+M_u+P_U$	$RR = R+S-T+M_D+P_D$
	$LL = -R-S-T+M_u+P_U$	$LL = -R-S+T+M_D+P_D$
	$RL = R-S+T+M_u+P_U$	$RL = R-S-T+M_D+P_D$
	$LR = -R+S-T+M_u+P_U$	$LR = -R+S+T+M_D+P_D$
(2)	$RR = R+S+T+M_u-P_U$	$RR = R+S-T+M_D-P_D$
	$LL = -R-S-T+M_u-P_U$	$LL = -R-S+T+M_D-P_D$
	$RL = R-S+T+M_u-P_U$	$RL = R-S-T+M_D-P_D$
	$LR = -R+S-T+M_u-P_U$	$LR = -R+S+T+M_D-P_D$
	$\overline{RR}-\overline{LL} = \overline{2S}+\overline{2(R+T)}$	$\overline{RR}-\overline{LL} = \overline{2S}+\overline{2(R-T)}$
	$\overline{LR}-\overline{RL} = \overline{2S}-\overline{2(R+T)}$	$\overline{LR}-\overline{RL} = \overline{2S}-\overline{2(R-T)}$
	$\Sigma_1+\Sigma_2 = 8M_U \quad \Sigma_1-\Sigma_2 = 8P_U$	$\Sigma_1+\Sigma_2 = 8M_D \quad \Sigma_1-\Sigma_2 = 8P_D$

TABLE 18—2

EXAMPLE OF ONE SET OF OBSERVATIONS (ON COBALT I). VERTICAL DRIVE.

A. Observations

Deflections in cm.

Mark Up

P	RL	LR	LL	RR	LL	RR	RL	LR
	−10 96	− 7 53	−18 06	− 0 27	−17 96	− 0 27	−10 93	− 7.60
(1)	10 95	7 66	17 97	0 26	18 04	0 33	10 78	7 56
	10 67	7 60	17 94	0 46	17 97	0 32	10 95	7 58
	−10 02	− 7 30	−17 83	− 0 24	−17 68	− 0 10	−10 58	− 7 37
(2)	10 63	7 23	17 68	0 20	17 76	0 07	10 64	7 53
	10 83	7 13	17 77	0 04	17 82	0 14	10 55	7 35

$(R + T) = 3\ 60$ $S_1 = 5\ 24$ $(R + T)_2 = 3\ 60$ $S_2 = 5\ 21$

Mark Down

P	RL	LR	LL	RR	LL	RR	RL	LR
	+ 7 34	+11 02	+ 0 50	+17 66	+ 0 24	+17 74	+ 7 37	+10 97
(1)	7 27	10 93	0 16	17 77	0 29	17 76	7 16	10 76
	7 19	10 76	0 17	17 86	0 17	17 74	7 22	10 85
	+ 7 20	+10 66	0 00	+17 46	+ 0 03	+17 36	+ 7 04	+10 68
(2)	6 87	10 53	+ 0 06	17 36	0 03	17 55	6 77	10 53
	6 90	10 63	0 03	17 47	0 06	17 47	6 85	10 46

$(R - T)_1 = 3\ 47$ $S_1 = 5\ 28$ $(R - T)_2 = 3\ 46$ $S_2 = 5.28$

$\psi = 1\ 572$ volt $Z = 1$ megohm $[\alpha = 1\ 007]$

B Results from Above Set of Observations

$e/m \times \rho_U = e/m \times (\rho + r)$	$e/m \times \rho_D = e/m \times (\rho - r)$	$e/m \times r$	$\rho\ e/m$	R_U	R_D	M_U/R_U	M_D/R_D	M/R	P_U	P_D
1 108	1 055	+0 026	1 082	+3 60 cm	+3 46 cm	−2 52	+2 57	−2 54	−0 13 cm	+0 15 cm

the rotor, or the end-for-end reversal of the drive when the axis of rotation was horizontal.

In Table 18—2, B, as in the corresponding parts of Table 20—1, below, M/R is the mean of the values of M/R and M_D/R_D, the sign of the second being reversed.

19. PROCEDURE IN MAKING THE PRINCIPAL OBSERVATIONS. All the observations were made on a regular time schedule. At the beginning of a particular minute on the clock, the rotor having been set at the predetermined position angle (1), and the galvanometer scale having been (slightly) shifted to zero, the switches were closed to produce the deflection *RL* (See § 18). An automatic signalling device caused a neon lamp to glow and a telegraph sounder to click at the end of a fixed interval (usually about 10^s or 8^s, according to the galvanometer circuits in use) after the switches were closed. The galvanometer was read at this instant, and the switches were then immediately opened.

From the beginning of the next successive minutes on the clock the procedure was repeated, except that the switches were set for the deflection *LR*, *LL*, etc., until the eight observations of the first line of Table 18-2 were completed. Then

the observations were repeated, in the same order, as indicated in the second and third lines.[7] The galvanometer drift was adjusted, if necessary, at the beginning of each line.

The whole set of 24 observations was then repeated, except that the rotor was set to start from a position angle (2) differing 180° from the previous angle (1). In the case of vertical drive, or in the case of horizontal drive with a single motor in use, the whole procedure was then repeated, but with the rotor reversed in its bearings.

When two motors were in use, drive by west or left motor and drive by east or right motor were interchanged instead of reversing the rotor. The next night, however, the complete process was repeated with the rotor reversed; but if the left (or right) motor was used first the night before, the right (or left) motor was now used first.

In many cases the time interval between successive observations was 2^m instead of 1^m; and in some cases it was $\frac{1}{2}^m$. In many cases the interval between the observation ending one line and that beginning the next was twice the interval between successive observations

In nearly all cases the electromotive force of the cell furnishing the standardizing current was measured for each set of observations In many cases the residual magnetic moment of the rotor was measured, often both at the beginning and at the end of the set.

20. THE PRINCIPAL RESULTS OBTAINED IN THIS INVESTIGATION. These are contained in Table 20—1.[8] The first column which requires comment is Col. 3. In connection with this column it should be said that in general all the different groups for a given rotor were not made consecutively, but were distributed (when there was a sufficient number of them) through the work so as to check, if possible, systematic errors which might be different for different conditions.

In Col. 4 the numbers in parentheses are the numbers of sets made in Part I, when the Inca coils were in use. Also, except those at the beginning and end of Part I, the observations were made with the Moll relay in use. These observations in Part I are probably inferior to the others. Also they give, on the whole, somewhat smaller values for ρ But they have been given equal weight with the others in making the calculations.

Col. 5 gives the mean values of $\rho e/m$ for all the sets, for both horizontal drive and vertical drive, in case both were used. Col. 6 gives the mean for both methods of drive, equal weights being attached to the two. Col. 7 gives the mean value when the observations in each group are weighted proportionally to their numbers There is little difference between the two.

Col. 8 gives the value of τ calculated on the assumption that the deflection T reverses with the reversal of the rotor's axis, and also with the change of drive from motor east to motor west, or vice versa, when two motors are used. The quantity does not represent an error, but represents the error which would be made except for the reversals introduced to eliminate it.

Col. 9 gives the quantity M/R, the mean of the values of M_L/R_L and M_R/R_R (or M_U/R_U and M_D/R_D), the sign of the second being reversed.

Col. 10 gives the mean value, without regard to sign, of the position angle deflection P to the gyromagnetic deflection R.

Col. 11 gives the quantity $L \equiv$ one-half the excess of $\rho\ e/m$ determined by observations with the left motor alone (for both directions of the rotor mark) over the corresponding value for the right motor. It does not represent an error, but represents the error which would result (in case of horizontal drive) if both motors were not used.

Col. 12 gives the quantity α which, for any rotor, turns out to be identical for the different coil arrangements used in the two methods of drive.

[7] Instead of three lines of observations, four lines were obtained in a number of sets—half with the galvanometer switch in one direction, half with the switch reversed.

[8] In addition to the results given in this table, two *partial* sets were obtained with the rotor Nickel IV, which was peculiarly susceptible to the effects of mechanical strain, and a number of sets with the rotor Cobalt II, which had worked quite satisfactorily in investigation I, but which showed great discrepancies in the present work. These results have been rejected pending further investigation of the sources of trouble. The mean values of $\rho\ e/m$ for both substances would have been increased by the inclusion of the results mentioned

TABLE 20—1

PRINCIPAL RESULTS OBTAINED IN THIS INVESTIGATION

1	2	3	4	5	6	7	8	9	10	11	12
Rotor	Drive	No Groups	No Sets	$\rho\, e/m$	*I* Mean $\rho\, e/m$	*II* Mean $\rho\, e/m$	τ	M/R	$\lvert P/R \rvert$	$L \equiv \frac{1}{2}(\rho_L - \rho_R)\, e/m$	α
Electrolytic Iron III	Horiz	8	25 (25)	1 020±0 017	[1 020±0 017]	[1 020±0 017]	+0 005 ±0 006	−0 39 ±0 002	1 4	−0 004±0 010	1 012
Electrolytic Iron IV	Horiz Vert	2 1	8 4	1 034±0 004 1 024±0 024	1 029±0 005	1 031±0 011	+0 014 ±0 010 −0 014 ±0 018	−0 15 ±0 03 −0 04 ±0 04	0 2 0 04	−0 016±0 014	1 030+
Norway Iron	Horiz.	1	4 (4)	1 028±0 011	[1 028±0 011]	[1 028±0 011]	+0 054 ±0 021	+0 22	0 3		1 015+
Steel III	Horiz Vert	1 1	4 (4) 6	1 045±0 009 1 035±0 007	1 040±0 005	1 039±0 008	+0 020[±0 010] +0 002 ±0 007	−0 37[±0 09] −0 38[±0 01]	0 07 0 03		1 006
Nickel I	Horiz Vert	6 1	24 (12) 1	1 050±0 030 1 067	1 052±0 008	1 052±0 030	+0 005 ±0 004 −0 011	−2 29 ±0 011 −2 45 ±0 05	0 30 0 25	+0 002±0 005	1 010
Cobalt I	Horiz. Vert	2 2	8 8	1 070±0 007 1 074±0 004	1 072±0 002	1 072±0 006	0 000 ±0 003 +0 027 ±0 004	−3 64 ±0 00 −2 71 ±0 11	0 12 0 03	−0 015±0 002	1 007+
Hopkinson's Iron—Nickel Alloy	Horiz. Vert.	2 2	8 (8) 11	1 018±0 012 1 019±0 019	1 018±0 000	1 019±0 016	−0 004 ±0 010 0 000 ±0 003	+1 89 ±0 03 +1 60 ±0 26	0 63 0 04	+0 002±0 006	1 049
Permalloy	Horiz Vert.	2 1	11 (11) 6	1 037±0 001 1 053±0 006	1 045±0 008	1 043±0 003	+0 004 ±0 001 0 000[±0 001]	+0 14 ±0 04 +1 22[±0 001]	0 72 0 01	+0 001±0 002	0 991
Cobalt-Iron	Horiz. Vert	2 1	16 (16) 6	1 028±0 011 1 030±0 004	1 029±0 001	1 029±0 009	+0 001 ±0 009 0 000[±0 003]	+0 46 ±0 00 +0 60[±0 04]	0 7 0 01	+0 009±0 001	0 994
Cobalt-Nickel	Horiz Vert	3 1	14 (6) 5	1 085±0 015 1 054±0 006	1 077±0 015	1 077±0 013	+0 014 ±0 006 +0 002 ±0 007	+0 11 ±0 16 −0 55[±0 00]	0 13 0 02	−0 006±0 004	1 022
Heusler Alloy (Cu, Al, Mn)	Horiz. Vert.	3 2	12 (12) 9	0 976±0 006 1 006±0 006	0 991±0 015	0 989±0 006	+0 001±0 002 −0 004±0 001+	+0 07 ±0 01 +0 05 ±0 01	1 3 0 05	0 000±0 002	1 052
										Mean $L \equiv \frac{1}{2}(\rho_L - \rho_R)\, e/m = -0\ 003 \pm 0\ 006$ for above 9 rotors.	

21. Comparison of the results obtained in this investigation with those obtained in the other investigations in the author's laboratories. The results obtained in this investigation (III) are compared with those obtained in I and II in Table 21—1. For this purpose all the soft iron rotors are grouped together in each case, likewise the cold-rolled steel rotors, and the cobalt and copper-cobalt rotors.

The most precise values are doubtless those obtained in II. The gyromagnetic ratios for soft iron and permalloy obtained in it are probably current to one-half per cent or less; the others to one per cent, or about one per cent.

TABLE 21—1

GYROMAGNETIC RATIOS OF FERROMAGNETIC SUBSTANCES VALUES OF ρ e/m FROM THE THREE EXTENSIVE INVESTIGATIONS IN THE AUTHOR'S LABORATORIES

(e/m = 1 759 e m.u)

Material investigated		Iron	Steel	Nickel	Hiper-nik	Hopk Al	Per-malloy	Cobalt	Cobalt-Iron	Cobalt-Nickel	Heusler Alloy
Investigation	Effect										
I	Barnett	1 049	1 047	1 031	—	1 016	1 054	1 070	1 067	1 068	1 011
II	Einstein-de Haas	1 032	1 038	1 051	1 051	1 023	1 046	1 085	1 025	1 076	—
III	Barnett	1 026	1 039	1 052	—	1 019	1 043	1.072	1 029	1 077	0 989
Mean I & III	Barnett	1 038 ±0 010	1 043 ±0 004	1 042 ±0 010	—	1 018 ±0 002	1 048 ±0 006	1 071 ±0 001	1 048 ±0 019	1 072 ±0 004	1 000 ±0 011
Mean of II and Mean I & III	Both	1 035 ±0 003	1 040 ±0 002	1 046 ±0 004		1 017 ±0 001	1 047 ±0 001	1 078 ±0 007	1 036 ±0 012	1 074 ±0 002	

For the materials studied in all three investigations the mean values of ρ e/m are as follows: (I) 1 050, (II) 1.047, (III) 1 045. The mean for (I) and (III) agrees exactly with the mean for (II). For the individual materials the means between I and III are given in line 6 of the table. The means between the values in II and those in line 6 are given in line 7. It is probable, however, that the values of III are more nearly correct than the means between I and III.

22. Comparison between results obtained in the author's laboratories and those obtained elsewhere. This comparison is made graphically in Fig. 22—1. The chart does not include the author's first observations by a magnetometer method (1917) on cobalt, nickel and iron, which, while useful in that they contained the first results on cobalt and nickel, and showed that the gyromagnetic ratios of these materials are nearly the same as that of iron, contained a (later detected) systematic error which made them certainly too large.

In the chart the abscissae, except for two substances, give the values of the gyromagnetic ratios from the author's investigation II, while the ordinates give the other results. In case of exact agreement with II any point would lie on the oblique straight line. The exceptional substances referred to are Heusler alloy and the oxides of iron, including magnetite. Heusler alloy was not studied (precisely) in II, so that the values obtained in I and III are placed as ordinates against their mean as abscissa. Magnetite and the other oxides of iron, not investigated by the author, are given the same abscissa as soft iron because the recent and extensive work of Ray-Chaudhuri on these substances shows that their gyromagnetic ratios are identical with that of iron within the limits of the experimental errors. The results of Sucksmith and Bates on iron and nickel have been slightly altered on account of the adoption in their work of a slightly incorrect method of calibration.

The close agreement between the results of III and II is apparent, also the generally good agreement between the results of I and II. The mean for iron in I is too high because the exceptionally large value obtained for the gyromagnetic

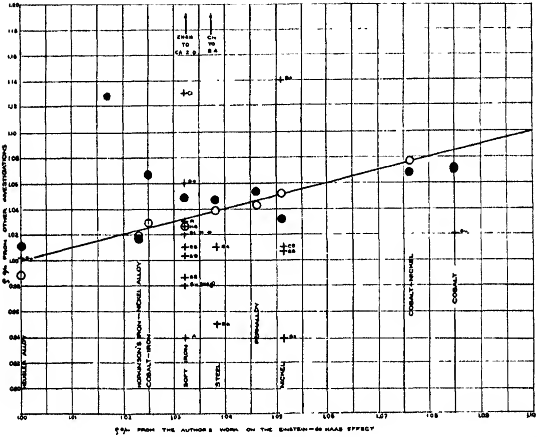

FIGURE 22-1. In this figure the empty circles refer to the present investigation (III), the full circles refer to the investigation I (Barnett & Barnett); the crosses followed by letters refer to other work as follows:

A stands for the work of Arvidsson (1919)
Ba stands for the earliest work of the author (1914 and 1915)
Be stands for the work of E Beck (1919)
Cl stands for the work of Claassen (1922)
CB stands for the work of Chattock & Bates (1923)
CS stands for the work of Coeterier & Scherrer (1933–1935)
EH stands for the work of Einstein & de Haas (1915–1916)
G stands for the work of Galavics (1939)
H stands for later work of de Haas (1921)
KG stands for the work of Kikoin & Goobar (1938)
R stands for the work of Ray-Chaudhuri (1935)
Su stands for the work of Sucksmith (1925)
SB stands for the work of Sucksmith & Bates (1923)
St stands for the work of J. Q. Stewart (1918)

ratio of electrolytic iron was included. The value for cobalt-iron in I is likewise high. It seems probable that both these chief discrepancies, and some others which occur, are due largely to the not quite complete elimination of errors caused by mechanical strain.

All the most recent values for iron and iron oxides, viz. those of Ray-Chaudhuri, Kikoin and Goobar, and Galavics, are in closer agreement with my value of $\rho\ e/m = 1.032$ for iron than could be expected from their authors' estimated errors alone. For the somewhat older value $\rho\ e/m = 1.00+$ of Coeterier and Scherrer no claim of precision is made.[9] This is likewise true for the larger and, as I believe, more nearly correct value of Galavics

[9] In the discussion at Strasbourg, Casimir, who was in Zürich while these experiments were being made, stated that the authors considered the possible error to be about 5 per cent

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THE FUTURE OF THE ACADEMY

In reviving the custom of an inaugural address, I have no desire to instruct my betters My state of mind is beautifully set forth in the opening sentences of the earliest communication presented to this society when, in 1780, Governor James Bowdoin, our first president, said· "When I consider, that among the members of the Academy there are gentlemen of abilities superior to my own, especially in the walks of philosophy, I feel a consciousness, that its honours might in one instance have been better placed. But if a defect of abilities could be compensated by a good will to serve its interest, and promote the end of its institution, I should have the satisfaction to think myself not wholly unqualified for the station, with which your suffrages have honoured me." Indeed, if any incoming president were inclined to be pretentious or puffed up, a glance at the names of his predecessors ought to deflate an over-extended ego Bowdoin, Holyoke, Bowditch, three members of the Adams family, James Jackson, Pickering, Bigelow, Asa Gray—these names adorn the first century of our corporate existence, and if he turns to later and living predecessors, he cannot be comforted There is a tale concerning John Adams, second president both of this body and of the United States, which is pertinent When Mr. Adams went to London as American minister, George III, who did not like rebels, said to him acidly· "You succeed Dr Franklin, do you not?" "No, sir" replied the diplomat, "I do not succeed Dr Franklin; I merely follow him." I do not succeed Harlow Shapley, I merely follow him

I have chosen to speak of the present status and possible future of the American Academy of Arts and Sciences. I have consulted nobody, and must bear the sole responsibility for any suggestions I shall make. If these suggestions are dismissed as proceeding from the valor of ignorance, I shall not complain Many of the problems before an institution like this are perennial, and the only novelty in successive decades is the varying emphasis with which they press upon us for solution Much that I shall say has probably been better said before. But I shall be content if my remarks awaken in my fellow academicians a sense of our present need for taking stock of the Academy, of ourselves, and of our individual relations to the corporate aim. I have scarcely met with the administrative officers of the Academy, so new am I to this office, but I believe it to be true that neither the President, nor the Council, nor the whole administrative body of the organization taken together, can work out a destiny worthy of our pretensions, unless the lively and continuing interest of a great majority of the fellows is awakened. Disagree with me if you will and denounce me if you must. But if I succeed in arousing debate over the general program of this historic institution I shall have achieved my purpose.

In a period when most educational institutions and many learned societies are taking stock, we, too, can afford to speculate But if we are to know what we are and whither we are moving, we ought to remember how we came into being and what we have been. The problems of a society like ours are in large measure the result of history It is therefore wise to glance briefly at the history of academies. That history falls into three grand divisions. In the first of these, academies came into being. In the second, they developed in certain important directions In the third, they lost ground. These three stages roughly correspond to the seventeenth, eighteenth, and nineteenth centuries.

Following the release of intellectual and cultural forces in the Renaissance, forces which eventuated as humanism or the New Learning, and the new science or Natural Philosophy, it is commonplace that in seventeenth-century Europe, leaders of what was then a radical reinterpretation of man and nature felt the need of mutual support and criticism, and that out of this need such institutions as the French Academy and the Royal Society were born. From their great example we descend. It is again a common-

place that one of the principal issues leading to the creation of these bodies was the necessity of finding or creating a language common to the new dispensation, more accurate than literary language, and better shaped for the purpose than was the technical vocabulary of scholasticism. Much of the theorizing which preceded or accompanied the creation of academies concerned this problem of word and meaning, much of the writing of Bacon, Descartes, and others concerned the problem of communication. They sought an instrument of language which should be at once rational, perspicuous, uncolored by personal emotion, and unperplexed by rhetorical adornment. Their assumption was that all parts of knowledge were equally accessible to any educated person, and that the reporting of experiment and discovery in simple, rational and perspicuous words would render the results intelligible to all who participated in the style. In sum, the kingdom of knowledge was indivisible, its language universal. Membership in the Royal Academy was therefore equally open to poet and scientist, who shared without embarrassment in its discussions.

In the eighteenth century another great addition was made. Specialization in certain fields—for example, chemistry and physics—had increased, and some differentiation of function was necessary. But knowledge was yet sufficiently uncomplicated for a universal genius like Franklin to follow where Bacon, Descartes, Leibnitz and Newton had led, and to contribute to a dozen fields, scientific papers that are models of exactitude in language that is simple and plain. As there seemed to be no reason why this situation should not continue, Franklin founded the first American learned society, with a particular ideal in mind Not research for its own sake, but research for social ends was the formal purpose of the American Philosophical Society held at Philadelphia for Promoting Useful Knowledge. The test of utility was social applicability. In striking contrast to the Renaissance doctrine that knowledge was a secret to be shared by the uninitiated only, the public diffusion of knowledge had now become a virtue.

This spirit presided over the creation of the American Academy of Arts and Sciences. If we turn to the preface to the first volume of our *Memoirs*, published in 1785, we read: "Societies for promoting useful knowledge may be highly advantageous to the communities in which they are instituted. Men united together, and frequently meeting for the purpose of advancing the sciences, the arts, agriculture, manufactures and commerce, may oftentimes suggest such hints to one another, as may be improved to important ends, and such societies, by being the repositories of the observations and discoveries of the learned and ingenious, may, from time to time, furnish the world with useful publications, which might otherwise be lost . . . Societies instituted for promoting knowledge, may also be of eminent service, by exciting a spirit of emulation, and enkindling those sparks of genius, which otherwise might forever have been concealed; and if, when possessed of funds sufficient for the purpose, they reward the exertions of the industrious and enterprising, with pecuniary premiums or honorary medals, many important experiments and useful discoveries will be made, from which, the public may reap the highest advantages."

This paragraph suggests that, the notion of social usefulness being granted, two important corollaries were drawn by the founding fathers. One was that the learned are under some obligation to hunt out and develop potential talent, and hence it is that academies established competitive prizes such as that, the winning of which first drew public attention to Rousseau. The second was that the proceedings of academies should be a public matter. In the seventeenth century learned men often communicated with each other by letter. Afterwards, the transactions of academies were published. The eighteenth century tended to transform these publications into periodicals which were important vehicles for the diffusion of knowledge to the enlightenment. Such periodicals served the eighteenth century for a variety of functions we have since differentiated, and were, in our terms, reports upon research and discovery, university monographs, extension lectures, correspondence courses, and technical trade journals. Because the fields of learning were still relatively close together, even when a mildly specialized magazine like *The American Journal of Science* was founded, under the shadow of academy practice it took all natural philosophy for its province.

And because universities were not yet what they have become, because industry was still simple, because research foundations were undreamed of, the academy remained a dynamic center for the intellectual world.

If the eighteenth century saw academies at their highest pitch of usefulness, the nineteenth saw their relative decline. The reasons are well known. The most obvious was the increasing differentiation of knowledge, the opening of vast new fields of research, the invention of new specialisms, and the development of unique technological vocabularies. The second was that government took over many of the functions originally developed by academies. The third was the development of the modern research university. The fourth was the creation of the independent research center, industrial laboratory, teaching museum, institute of advanced studies, or other endowed project for the advanced specialist. The fifth was the establishment of gigantic foundations like the Guggenheim Foundation, to search out and support younger research workers or to reward them with prizes and fellowships on a scale beyond the resources of academies.

As a consequence, the academy lost ground. Because specialization of knowledge was accompanied by specialization of vocabulary, one of the first results was to drive the scientist and the humanist apart, so that in the case of our own organization (as an example) humanists tend to stay away from a scientific communication on the ground that they connot understand it. A minor, but unfortunate, result, has been that scholars in the arts have set enthusiastically to work to become as linguistically complicated as the scientists, thus insuring that the scientists could not understand *them*. Eventually, of course, scientists were driven apart from each other.

A second, and more fundamental, change occurred when (the old, undifferentiated academy meeting proving unsatisfactory to the new specialisms), the century developed the greatest number of professional associations the world has ever known. These in turn increased by fissure into still more specialized organizations, so that, to take a simple case, we have not merely the American Historical Association, but within that society or associated with it, groups like the Catholic Historical Society, the Mississippi Valley Historical Society, a group in agricultural history, a group in local history, a group in military history, and so forth. And precisely as the undifferentiated academy meeting proved unsatisfactory, so undifferentiated publications proved also unsatisfactory, and academy publications must now therefore compete with technical and professional journals so infinite in number as to reduce librarians to despair.

The rise of the modern research university has further narrowed our field. It has not merely created, in laboratory and library, centers of personal contact among research workers far more useful than an academy building can hope to be, but it has also given us attractive training centers for young men. Graduate fellowships are a more satisfactory method of encouraging young talent than random academy prizes can become. Moreover, the publication of dissertations, monographs, and books of greater magnitude, at university expense removes from academy lists titles that might otherwise be there, and throws academy publication into competition of the severest sort. Finally, but in the long run most importantly, the universities have developed techniques of begging gifts from the wealthy that leave the simple-minded academician gasping in the rear.

The competition of government bureaus is equally interesting. The early years of the American Philosophical Society and of this academy saw its members writing papers about the weather, tides, weights and measures, geology, mastodons and other topics that, one by one, became the professional province of the Weather Bureau, the Coast and Geodetic Survey, the Bureau of Standards, the Smithsonian Institute and other parts of the national government. These agencies can accomplish cooperatively what, with all their genius, individuals like Franklin and Jefferson could not achieve. Government bureaus are subsidized by public money, the academy is not; and by definition they take over from the academy a role of public service and public education that was one of the original aims of our institution. To be sure, distinguished members of the government services become members of the academies, but this is not the same thing as assuming that the primary aim of an academy is the public service. Finally, of course,

government publication competes with academy publication.

Modern industrial research has further complicated our survival problem. Not to speak of the vast equipment ready for the research worker in industrial laboratories, and of the money which can be placed at the disposal of such a laboratory, once it has struck a promising lead, the ambivalent attitude of large corporations towards the results of research they have subsidized must be reckoned with. Some corporations are conspicuous for their sense of civic responsibility; others, it is notorious, buy up brains and hoard discoveries. This latter practice exactly contradicts the generous eighteenth-century belief that the diffusion of rational knowledge is the highest ethical obligation upon the expert; and where the practice of monopolizing research exists, it marks the failure of academies to convert the nation to a right philosophy. More important, however, is the fact that if industry finds it profitable to subsidize its own laboratories, it is not going to donate money to academies except upon terms that are agreeable to industry, and such donations, when they come, are more likely to be for specific projects than for the general public weal.

It would be tedious to rehearse the tale of other agencies which have innocently weakened the influencies of academies. Textbook publishers are a single instance. Nor should it be assumed that academies are obsolescent. In an age of big money, when an ancient institution like the American Philosophical Society is given a large bequest, it wonderfully renews its youth. But if one looks at the general history of academies hopefully founded during the last two centuries, two observations will occur. The first is that many of these, especially those limited to a state or region, have been absorbed by some nearby university as an extramural outlet for research papers, or have become social bodies. The second is a tendency to make election something between an honorary degree and retirement, a recognition of things accomplished rather than a spur to greater things. This danger was recognized by our academy in 1921 when a special committee wisely reported: ". . . it is the duty of the Academy, and its privilege, to encourage work in the Arts and Sciences and to be, through its meetings, a center for getting together once a month a large number of persons interested in learning here in Boston. Reasonably prompt election of young men in this vicinity will aid in the accomplishment of both these purposes. We believe, however, that no one should be elected to the Academy who has not in his own name and by his own determination, already given good evidence, through his publications, of accomplishment, and further evidence of the promise of accomplishment in the future." Because war conditions have taken many younger men away from us, it is perhaps well to recur to the sound advice of the committee and to remember that the reasonably prompt election of young men in this vicinity is one of the most important guarantees that we shall not become senescent.

No one can say, I think, that in 1900 academies were as important in the total intellectual life of a nation as they had been in 1800 or in 1700. All the forces leading to the fractation of knowledge have been more vigorously operative in the last forty years than ever before. Nevertheless, two developments in the twentieth century have indicated an opposite trend. In some sense specialism has defeated itself. That is to say, what once looked like a separate compartment of knowledge, unique and apart from everything else, the more it is explored, the more its boundary lines seem to waver and vanish. The relation of fields is not that of pigeon-holes, but of living, interdependent cells. The historian depends upon the anthropologist, the anthropologist upon the sociologist, the sociologist upon the psychologist, the psychologist upon the biologist, the biologist upon the chemist, the chemist upon the physicist, the physicist upon the mathematician, and so on in an endless circle. It is hard to know whether a given problem lies in chemical physics or physical chemistry. I am supposed to be a literary critic, but I seem to spend most of my time with the historians. In certain advanced areas it is difficult to know whether one is confronting mathematics or theology. The area and language programs of the Army have fused into a common purpose a dozen so-called "disciplines." These random examples show how the very multiplication of specialities has forced the specialists to come together, to exchange ideas, to study each other's techniques, even—what is anathema to the old-fashioned, hard-boiled,

realistic investigator—to discuss the philosophy of what they are doing.

And a second pressure towards unity has come from the outside. Students of Western culture have freely said that if we do not recover a common set of ideas, a common tradition, and a common language, we are lost The wheel has come full circle, but on another plane; and just as men sought in the seventeenth century a means of communicating with each other that would permit the easy flow of generalized ideas, so we, too, perhaps face the same necessity Certain it is that in any meeting convoked to discuss the state of culture or of education, it is common to lament that knowledge is specialized, to compare its fractation unfavorably with the medieval synthesis or with classical unity, and to demand that we retrace our steps or learn some new mode of common speech.

Much of this appeal, to be sure, is specious Much of its springs from a nostalgia after a perfect past that never was. Neither classical culture nor the medieval world embraced a fraction of the human beings alive under either dispensation, and the middle ages were not so synthesized nor classical minds so harmonious as this argument seems to imply. Nevertheless, it is an argument of weight, and the question is only. what knowledge is to be intercommunicated, and where can this intercommunication best take place? Let me glance at these problems in reverse order.

Government and industry aside, there are, it seems to me, three sorts of institutions in which specialists might talk to each other, and to some extent do so perform· universities; specially called congresses; and academies. The universities seem at first sight favorable places None but has its committee on curricular reform. This reform takes the direction of something called "broad" courses, intended to synthesize knowledge for the young, and presumably indicates that their elders feel the need for synthesis. But the confusion of that which is broadening with that which is broad, has never been cleared up by the reformers, and it is amusing to note that this movement mostly creates a new type of educational specialist, the synthesizer On the whole, moreover, this movement does not affect the mature work of the university, which is that of graduate training and of research. The creation of specialists *is* the professional purpose of universities, and should not be altered. Therefore, laudable though the aim of the reform may be, it seems unlikely that university faculties, to whom research is the principal reward of their intellectual being, will cease to be specialists. But as specialists will they seek to communicate with each other? Yes and no, but I think "No" rather more than "Yes." What stands in the way of organic change is the economic structure of the American university. The basic unit of faculty organization is the department; and however we may pretend that a department is only a committee of the faculty, the truth is, of course, that departments are in grim financial competition with each other, engaging in a kind of *bellum omnium in omnes* for salaries, research funds, promotions, appointments, and endowment. In a universe of experts the unspecialized goes to the wall The specialist cannot desert the professional flag, and must, *ex hypothesi*, stick pretty well to his department.

The next possibility is the special congress, of the type of the Conference on Science, Philosophy and Religion annually convoked at Columbia University. That these yearly meetings accomplish something in cross-fertilization and cross-simplification is probably true, but in the nature of the case their influence is intermittent and appeals only to the people to whom it appeals. Moreover, these congresses sometimes produce effects the opposite of what they intend. Their search for a common language leads to the creation of elaborate verbal structures that, in seeking accuracy, achieve a new complexity, and this search for absolute definitions throws emphasis upon techniques and procedures rather than upon ideational content Their second weakness is an inevitable tendency towards evangelicism, which is socially laudable but not the same thing as using a language common to all disciplines. Let us not forget that one of the aftermaths of the International Congress of Religions at the World's Columbian Exposition was an increase in the number of sects.

An academy, however, is free from the internecine warfare of the departments and is a more stable body than the annual congress. There being no problems of promotion or salary increase

to disturb our republican simplicity, we ought to be an institution in which specialists can relax; and as we are committed to serve, but not to remake, the body politic, our processes can be ideological rather than passionate. Nevertheless, our usefulness is also severely limited, and unless we are prepared courageously to face these limitations, we may yet join other venerable Boston organizations of historical importance only. If this be treason, make the most of it.

In shaping this academy our predecessors recognized even in simpler times the differentiation of knowledge, by establishing the several classes and divisions of our membership. Yet, except as a device for maintaining balance in electing new fellows and except for fulfilling certain constitutional provisions, the academy seems not to recognize the problem set by its own organization. Our aims are contradictory. On the one hand, our monthly "communications," operating on eighteenth-century postulates, are supposed to be couched in such language that all sensible men can understand them On the other hand, we exist for the advance of knowledge in the several fields represented by our sub-sections, the heritage of the nineteenth century. If a fellow presents the results of research in his specialty, it is possible that only members of his own class and subsections will fully comprehend him; yet if his research is to receive competent criticism by the academy, he ought not abate one whit of its intricacies, albeit in proportion as he is accurate and detailed, his audience will necessarily diminish. On the other hand, if members address the general meeting, as they do, they cannot hope to present specialized problems without simplification, thereby running the double risk of wearying the competent and of talking down to the uninitiated. Good sense, to be sure, gets many a speaker around this difficulty, and the very challenge of the occasion sometimes compels a useful clarification. Nevertheless, here is a difficulty which severely limits the program committees in its choice of speakers and of topics. It is also a difficulty which leads to eccentric results in the size and character of academy audiences.

But what most troubles me is not these pragmatic considerations, but the begging of the question of the relation of the academy to research. I do not believe we exist for the amiable exchange of lectures. I thing our primary duty is still that of our charter, which is "to promote and encourage . . . knowledge . . . and . . . to cultivate every art and science, which may tend to advance the interest, honor, dignity and happiness of a free, independent, and virtuous people." As I understand this language, it says that the cultivation of our several departments of work is the primary duty of the Academy, which, by bringing mature men and women together in their several fields, seeks to encourage their investigations. So far as we are under any obligation to inform the general public about what is going on in our separate specialties,—and that it is a duty I grant—that duty nevertheless seems to me secondary to our principal purpose—our directive, in modern lingo. But I am frank to say our meetings do not always carry out that principal purpose I am by no means clear that our present type of monthly meetings is the sole type of program we can usefully support; and if we have to choose, I think we ought rather to imitate the work of the Institute of Advanced Studies at Princeton than the work of the Lowell lectures, excellent for their purpose though these latter may be. In short, I suggest the time has come to re-study the whole question of the nature, number, and function of our monthly "communications."

But if the encouragement of research is the primary business of the academy, what, it will be asked, becomes of the hunt for a common language? If I raise the question whether the present pattern of our meetings efficiently carries out the original aim and primary purpose of this society, I must not be understood as saying that all our gatherings should be devoted to matters so technical that only a few can comprehend them. I am far from implying that our general meetings should disappear. But they should not be our only type of meetings. I do most firmly believe that the spirit of research at advanced levels rather than the spirit of reporting even at high levels is essential to the healthy life of an academy. I do not see how we can hold the real attention of younger members unless we somehow vigorously implement the statement of the 1921 committee that this academy must be a center of learning in Boston. If we attempt to reduce complex problems of investigation to postulates

so simple that all the members of the Academy will immediately understand them, I do not believe young specialists are going to keep up an eager interest in our meetings. I therefore suggest that to study the problem of differentiating our meetings, to compare our success with that of the American Philosophical Society, which, as most of you know, follows a different plan, to review the purpose and function of these meetings, and, indeed of the Academy as a whole, seems to me primary business of our immediate future.

But I may seem to depart from the notion that academies exist in order that learned men may talk a common language. As I earlier indicated, this call to retreat up the stream of time to simpler eras seems to me specious I do not believe such a retreat is practicable. I think the problem is wrongly phrased. I should myself put it this way: that our problem is not whether a common language can be artificially reinstituted among learned men, but whether this Academy is not charged with the duty of creating a common climate of opinion. My observation is that the research spirit does not depend upon vocabulary but upon an exciting philosophy of values. In my wanderings over the republic it has seemed to me that those institutions were stimulating, not where the chemists were concerned lest the literary critics could not understand them, but where the chemists and the literary critics were alike committed to an exciting intellectual existence I think institutions of learning grow or decline, are active or dormant, in proportion as they dare to foster great projects, dream of great issues, and dare to embark upon great and important programs. Will the American Academy of Arts and Sciences rise to the height of the great argument which brought it into being, or will it be content to become simply another Boston institution?

To be sure, we at present offer prizes and subsidize research projects in proportion to our modest means. That is all to the good. If we do not do better, our excuse is: lack of funds. I do not question the utility of our present practice, but it is utility on a lower level. I shall be bold enough to say bluntly that this academy does not now foster enterprises of that magnitude and daring the founding fathers had in mind when they wrote in 1785: "It is the part of a patriotic philosopher to pursue every hint—to cultivate every enquiry, which may eventually tend to the security and welfare of his fellow citizens, the extension of their commerce, and the improvement of those arts, which adorn and embellish life." In an age committed to cooperative enterprise, we who are, or ought to be, the pattern of cooperative enterprise in New England intellectual life must realize our opportunity. We must think largely and generously, not in terms of *ad hoc* projects and parochially. What enterprises can we foster? What is our potential contribution as a corporate body to the life of Boston, of Massachusetts, of New England, of the nation? Dare I say that in any realistic census of the intellectual forces at work in the dominion of New England this academy would not now possess that commanding and central place it ought to have? But we should not be simply another Boston society, we should be *par excellence* the commanding intellectual institution in all the New England states In place of searching the rolls of colleges and of industry for new members, we should have colleges and industry searching our membership for talent. In place of requesting Dr X or Professor Y to tell us what is going on in the Massachusetts Institute of Technology or at Washington or in the Museum of Fine Arts, we should have M. I. T. and Washington and the Museum anxiously and hopefully inquiring: what is forward at the American Academy of Arts and Sciences? We have, or had, or should have, a central position in New England culture; is it conceivable that this academy may again become a dynamic center from which lines of intellectual energy shall radiate to all parts of these states and even to the nation at large? I do not believe it is the excitement of the moment that leads me to say that the future before the American Academy is immense, provided the Academy will bestir itself. But it cannot remain passive. It must renew its life. It must announce programs of imaginative daring. It must not indulge that spirit of historical defeatism which a newspaper man has just told me is characteristic of Boston.

It will be said that money and time are lacking, that existing institutions, already heavily endowed, absorb potential funds and monopolize public attention. This is a weak argument. Money never comes to the timid, just as it never

comes to the planless. But if a millionaire came to this building tomorrow to inquire what the Academy had in mind, what could we say to him as a corporate body? No one is going to give to the Academy on the ground that it is vaguely a good thing to support. Only a dynamic program will attract attention to us. And though I would by no means confine the activities of our fellows to any restricted sphere, I am going to crown these audacities by suggesting one form of activity in which the Academy could make itself felt at once.

Boston, Massachusetts, and New England face difficult years, and so far as I can discover, no single body is at work to study the problems immediately ahead To be specific· we do not know what to do with or for the Port of Boston. We do not know how to relieve the racial and religious tensions among us We do not know what to do with the apparently moribund agrarian economy of New England. We do not know whether our industries can continue as they have been We do not know precisely what our natural resources as a region are If this meeting were held in Chapel Hill, North Carolina, it would be unnecessary for me to say that a survey and a study of the problems of the region at our doors is a primary obligation upon a learned body of disinterested men living in that region. As it is, I suggest that if, after mature consideration of these possibilities, the American Academy of Arts and Sciences were to announce in the public prints that it proposed to embark upon a generous and long-range study of these, and allied, problems, making public the findings of expert members of its body and having no further ax to grind than that of fulfilling the injunction of its founders to bring such information to bear upon our social life as may eventually tend to the security and welfare of our fellow citizens—I say, if the Academy, after mature deliberation, should announce this as one of its present aims (but by no means the only one) I am convinced the tonic effect upon the Fellows and upon the region in which we live would be immense. I venture to prophesy that money and means could be found. I venture to suggest, in fact, that we may even be under some obligation not to stand passive when the economic, the social, and the intellectual life of the commonwealth needs study and support.

Such a project might revolutionize some of our activities, but I do not say that it should revolutionize all of them. I do not argue that our astronomical Fellows should calculate the orbit of the next comet only with reference to Newbury Street. But I feel profoundly that the American Academy of Arts and Sciences is one of the great enterprises descending from the eighteenth century, and I am deeply concerned that it should fulfill the measure of its greatness I think it should have a place in the life of this commonwealth comparable to that of the Boston Symphony Orchestra, the Massachusetts General Hospital, or the great colleges, institutes and universities round about, which it would be invidious to particularize. I am concerned lest we shall be without vision. I am uneasy lest we break into disparate entities and fail of common purpose I should like to see us launch greatly upon great enterprises. Unfortunately neither a scientist nor a social scientist, I cannot sketch a specific program of action, but I most earnestly hope these suggestions will be taken up by Fellows competent, as I am not, to translate them into action.

I believe we should create a specially appointed commission of Fellows of the Academy to review and re-examine the whole structure of this ancient institution. Without prejudice to the admirable work of the Council, the Secretaries, and the standing committees, I think this commission should be a special and independent body, having (within the limits of our treasury) funds at its disposal to implement its study, by travel, by calling upon witnesses, and by such other means as seems necessary. I think it should in good time bring in a printed report of such depth and magnitude as will bring immediately home to each of us the problem of the Academy and its future in a world that may seem to have outgrown these primitive institutions. I suggest this body might take as its principal inquiries these:

1 The nature of the organization of the Academy and of its meetings, in relation to the furtherance of research and of intellectual cooperation in New England.

2. The responsibility of the Academy for the intellectual life of New England, and the possibility of making this body and the building in increasing degree a focal point for joint enterprises, cooperative projects, and the like.

3. The question of the Academy building—cannot it be repaired and modernized so that it will better further the purposes of the Academy?

4. A campaign for increasing the endowment of the Academy, having in mind specific programs upon which the Academy may fruitfully embark.

This is, I know, ambitious. It may seem to many of you vague. Perhaps I am raising these questions in the wrong place or in the wrong way or at the wrong time. But I have a feeling that what we determine to do in the next two or three years will powerfully influence our whole future existence; I have a feeling that, rich as is New England in institutions of learning, they will welcome some positive program to link together the interests of the learned and the problems of society in the years immediately to come, and I earnestly desire that the American Academy of Arts and Sciences, the second oldest learned society in the United States, should assume the captaincy and take the lead because, it seems to me, history and tradition say that it should do so.

RECORDS OF MEETINGS

One Thousand Two Hundred and Eightieth Meeting

OCTOBER 14, 1942—STATED MEETING

The Academy met at its House at 8.25 P M.

The President in the Chair

This meeting has been designated as Ladies' Night, and there were present 250 Fellows and guests.

The records of the meeting of May 13 were read and approved.

The following communications were presented

George Sarton: "Leonardo, Man of Science."

Otto Benesch: "Leonardo da Vinci and the Beginning of Scientific Drawing"

Dr. Benesch also arranged an exhibit of reproductions of some of Leonardo's scientific drawings, consisting of facsimiles loaned by the Fogg Art Museum and of illustrated books loaned by the Harvard University Library.

The meeting was dissolved at ten o'clock.

One Thousand Two Hundred and Eighty-first Meeting

NOVEMBER 18, 1942.—STATED MEETING

The Academy met at its House at 8 27 P M.

The President in the Chair.

There were present thirty-three Fellows and eighteen guests.

In the absence of the Recording Secretary, the Corresponding Secretary acted as Recording Secretary *pro tem.*

The records of the meeting of October 14 were read and approved.

The Corresponding Secretary reported the receipt of letters accepting Fellowship from Francis Birch, John Nash Douglas Bush, William Irving Clark, Samuel Cornette Collins, Donald Kirk David, Howard Sylvester Ellis, Russell Gibson, Roger Sherman Greene, Otto Kinkeldey, Wassily W. Leontief, Samuel Albert Levine, Richard Peter McKeon, Daniel L. Marsh, William Ralph Maxon, Hermann Joseph Muller, William Andrew Paton, Paul Anthony Samuelson, and Otto Struve; also a letter accepting Foreign Honorary Membership from Lorenzo Raimundo Parodi.

He also reported the receipt of letters resigning Fellowship from Edward H. Chamberlin, Henry T Lummus and Edgar H. Sturtevant.

A vote was then taken on a proposed amendment to the Statutes, Chapter II, Article 2, which had been recommended to the Academy by the Council at the annual meeting last May, as follows

"Fellows of the Academy on retiring from their academic or other regular duties may, if they so desire and with the approval of the Council, be transferred to the status of Fellows Emeriti. Fellows Emeriti shall be exempt from the payment of dues and may not hold office in the Academy, but shall have all the other privileges of Fellowship. In the published lists of the membership of the Academy, Fellows Emeriti shall be separately classified and shall be outside the statutory limit set on the number of Fellows."

This amendment was adopted by a vote of twenty-eight in favor and one against.

The following communication was presented.

Charles W. Eliot, 2nd. "City Planning."

The meeting was dissolved at 9 46 P M.

One Thousand Two Hundred and Eighty-second Meeting

DECEMBER 9, 1942—STATED MEETING

The Academy met at its House at 8 30 P. M.

The President in the Chair.

There were present forty-one Fellows and twenty-one guests

The records of the meeting of November 18 were read and approved

The Corresponding Secretary reported the receipt of a letter from Gordon W. Allport, resigning Fellowship

The following communication was presented:

Ross A. McFarland "Human Problems in Aviation," illustrated with slides and moving pictures.

An exhibit in the Reading Room showed recent astronomical discoveries. a first magnitude nova, a new comet, evidence for a planet in another stellar system.

One paper was read by title: "The Advent of the Microscope in America, with Notes on its Earlier History," by Frederic T Lewis.

The meeting was dissolved at 10 10 P. M

One Thousand Two Hundred and Eighty-third Meeting

JANUARY 13, 1943—STATED MEETING

The Academy met at its House at 8 25 P M

The President in the Chair

There were present thirty-nine Fellows and sixty-one guests, many of them headmasters of public and private schools, who had been specially invited to this meeting

The records of the meeting of December 9 were read and approved

The Corresponding Secretary reported the receipt of a letter from Henry J Cadbury accepting his election to Fellowship

He also announced that the Council had appointed Melvin T Copeland and Edmund M. Morgan to fill the vacancies in the Council created by the resignations of Edward H. Chamberlin and Edward S. Thurston, for the rest of the academic year.

The following communication was presented

Henry M. Wriston "The Problem of the Liberal Arts College"

In the Reading Room there was exhibited a selection of notable specimens of mathematical texts, printed in each century from 1500 to the present.

The meeting was dissolved at ten o'clock

One thousand Two Hundred and Eighty-fourth Meeting

FEBRUARY 10, 1943—STATED MEETING

The Academy met at its House at 8 29 P M.

The President in the Chair

There were present thirty Fellows and fourteen guests

In the absence of the Recording Secretary, the Corresponding Secretary acted as Recording Secretary *pro tem.*

The records of the meeting of January 13 were read and approved

It was announced that a special meeting was to be held on April 6 in honor of Governor Bautista and Ambassador Najera of Mexico.

The following communication was presented:

Paul C. Mangelsdorf: "Economic Plants as Weapons of War."

An exhibit of photographs, drawings and materials collected on the site of the Boylston Street Fishweir, was described by Dr Frederick Johnson

The meeting was dissolved at 10.02 P M.

One Thousand Two Hundred and Eighty-fifth Meeting

MARCH 10, 1943—STATED MEETING

The Academy met at its House at 8 34 P M.

The President in the Chair.

There were present forty-eight Fellows and twenty-six guests

In the absence of the Recording Secretary, the Corresponding Secretary was asked to assume his duties

The records of the meeting of February 10 were read and approved

It was announced that the President had appointed the Nominating Committee, as follows.

Ernest H Huntress, of Class I
Ivan M Johnston, of Class II, *Chairman*
Dumas Malone, of Class III
S Foster Damon, of Class IV

On the recommendation of the Council the following appropriations were voted for the year 1943–44

From the income of the General Fund, $6,825, to be used as follows:

for House expenses	$2,200
for General and Meeting expenses	900
for Library expenses (salaries, books, periodicals and binding)	2,625
for Treasurer's expenses	1,100
	$6,825

From the income of the Publication Funds, $2,000, to be used for publications.

From the income of the Rumford Fund, $3,000, to be used at the discretion of the Committee.

From the income of the C M. Warren Fund, $750, to be used at the discretion of the Committee.

The President announced that there would be a special meeting on April 6, in honor of Governor Gonzalo Bautista, of the State of Puebla, Mexico, and Ambassador Najera, and that this would take the place of the regular April meeting.

The following communication was presented:

Manley O. Hudson: "International Organization after the War"

The meeting was dissolved at 10.04 P M.

One Thousand Two Hundred and Eighty-sixth Meeting

APRIL 6, 1943—SPECIAL MEETING

A special meeting was held at the House of the Academy at 8 30 P. M at which the guests of honor were Dr. Gonzalo Bautista, Governor of the State of Puebla, Mexico, and His Excellency, the Mexican Ambassador Nearly three hundred persons were present, including members of the Pan-American Society of Massachusetts, and members of the families of Fellows

The program was as follows

Presentation of the greetings of the Academy to its guests President Shapley

Response by Governor Bautista.

Address "Mexican-American Cultural Relations" Ambassador Najera

Address "Earthquakes, Volcanoes and Mountain Systems of Mexico" Professor Kirtley F Mather

Reception in honor of the Governor and the Ambassador

There was a special exhibit of reproductions of pre-Columbian Mexican manuscripts, and another of seismograms.

This meeting took the place of the stated April meeting of the Academy, which would have been held on April 14

One Thousand Two Hundred and Eighty-seventh Meeting

MAY 12, 1943—ANNUAL MEETING

The Academy met at its House at 8 22 P M.

Vice-President Robinson in the Chair.

There were present forty-four Fellows and twenty guests.

The records of the meetings of March 10 and April 6 were read by the Corresponding Secretary in the absence of the Recording Secretary and approved by the Academy.

The Corresponding Secretary made the following announcements from the Council·

The Permanent Science Fund Committee has been reappointed. John W. Bunker, *Chairman,* George R. Agassiz, Kenneth T. Bainbridge, Gregory P. Baxter, Charles T. Brues, Hudson Hoagland, Walter S Hunter, S Burt Wolbach.

The following grants have been made from the Permanent Science Fund

1 To Elso S Barghoorn, Jr., Instructor in Biology, Amherst College, for expendable materials, compensation for assistance, and field expenses in a continuation of his studies on the structural and mechanical changes which occur in submerged wood and other plant remains, $350

2 To Alfred Rehder, Curator of the Herbarium, Emeritus, Arnold Arboretum, for one-half the cost of library work in various cities for completion of the manuscript on the Bibliography of Cultivated Trees and Shrubs, $100

Professors Edward K Rand and Carl N. Jackson have been transferred to the status of Fellows Emeriti, in accordance with the amendment to the Statutes adopted by the Academy in November 1942

A letter has been received from Wilmer Lanier Barrow accepting his election as a Fellow.

At a special meeting of the Council on April 20, the following were elected to Fellowship in the Academy·

CLASS I

Section 1	Edwin Powell Hubble, Pasadena, Cal
	Cecilia Helena Payne-Gaposchkin, Lexington
Section 2	Enrico Fermi, Leonia, N. J
	Philipp Frank, Cambridge
	Edwin Herbert Land, Cambridge
	Donald Charles Stockbarger, Belmont
Section 3	Hugh Stott Taylor, Princeton, N J
Section 4	Bradley Dewey, Cambridge

CLASS II

Section 1.	Lewis Don Leet, Harvard
Section 3	David Bruce Dill, Arlington
	Brenton Reid Lutz, Melrose
Section 4	Arlie Vernon Bock, Cambridge
	Chester Scott Keefer, Brookline

CLASS III

Section 1	Charles Edward Wyzanski, Jr., Brookline
Section 2	Payson Sibley Wild, Jr , Cambridge
Section 3.	Augusta Fox Bronner (Mrs. William Healy), Boston

	Benjamin Morris Selekman, Cambridge
Section 4	Ada Louise Comstock (Mrs. Wallace Notestein), Cambridge

CLASS IV

Section 1.	Angus Dun, Cambridge
Section 2	Carleton Stevens Coon, Wakefield
	Hugh O'Neill Hencken, Chestnut Hill
Section 3.	Perry Gilbert Eddy Miller, Cambridge
	Jean-Joseph Seznec, Cambridge
Section 4	Leonard Bacon, Peace Dale, R I.
	Willa Cather, New York, N. Y
	Randall Thompson, Charlottesville, Va
	Thornton Niven Wilder, New Haven, Conn

The following reports were presented

REPORT OF THE COUNCIL

Since the last report of the Council the deaths of twenty-one Fellows have been reported Joseph Henry Beale, Stephen Vincent Benét, Franz Boas, Ralph Adams Cram, John Frank Daniel, Davis Rich Dewey, Frank Edgar Farley, James Edmund Ives, James Richard Jewett, John Ellerton Lodge, Abbott Lawrence Lowell, Charles Thomas Main, Edward Caldwell Moore, George Andrew Reisner, Robert Wilcox Sayles, Charles Schuchert, Andrew Watson Sellards, William Albert Setchell, Joseph Warren, Grenville Lindall Winthrop, Joseph Ruggles Worcester, and of four Foreign Honorary Members Frank Dawson Adams, Sir Joseph Larmor, Charles Tate Regan, Richard Willstatter.

Twenty-one Fellows and one Foreign Honorary Member were elected by the Council and announced to the Academy in May 1942.

The roll now includes 773 Fellows, 2 Fellows Emeriti, and 119 Foreign Honorary Members (not including those elected in 1943).

REPORT OF THE TREASURER

*RECEIPTS

Academy, General			
From: Investment Income (Schedule D)	$12,507 28		
Less. Income to Special Funds	9,548 95	$2,958.33	
Assessments and Admission Fees		4,175 00	$7,133 33
Amory Fund Committee			
From: Investment Income			$2,913.87
Publications Committee			
From Investment Income		$2,384 53	
Sale of Publications		682 50	
Rumford Fund		720 00	
Subscriptions, Lake Publication . .		255 80	4,042 83
Rumford Fund Committee			
From Investment Income			3,061 00
Warren Fund Committee:			
From: Investment Income			967 73
Mabel S Agassiz Fund			
From Investment Income			111 20
Permanent Science Fund			
From Boston Safe Deposit and Trust Co, Trustee		$15,946.62	
Return of balance of Grant		21 03	
Investment Income		47 26	16,014 91
Kennelly Fund			
From Investment Income			63 36
Total Receipts			$34,308.23

†EXPENDITURES

Academy, General:			
Library, Salaries	$2,048 00		
Books & Binding (Net)	362 58	$2,410 58	
General (Net)		861 45	
House (Net)		2,559.46	
President's Office		7.50	
Treasurer's Office		539 35	
Insurance		605 79	$6,984.13

* Excluding sales of securities.

† Excluding purchases of securities.

Amory Fund:		
Expense		$48.00
Publications Committee.		
General	$3,496 72	
Lake	174.39	
		3,671 11
Rumford Fund Committee.		
Grants	$400 00	
To Rumford Fund	720.00	
		1,120 00
Warren Fund Committee		
Grants		700 00
Mabel S. Agassiz Fund		
For Meetings		111 20
Permanent Science Fund		
Grants	$1,585 00	
Expense	1 65	
		1,586 65
Special Expense		
Recording Secretary		27.40
Total Expenditures		$14,248 49

Report of the Library Committee

In addition to the many volumes and serials consulted at the Academy within the past year, there were borrowings by eighteen outside libraries. Of the total of 87 volumes and 16 unbound numbers borrowed, very few were taken out by Fellows of the Academy, and the inference is not unwarranted that the resources of our Library are perhaps better realized from without than from within our walls.

The addition of 217 volumes since last year's report brings the number on the shelves to 47,114. Of the additions, 153 were received by gift or exchange and 64 were purchased. Most of the items purchased were parts of serial sets from the Library of the Boston Society of Natural History, filling gaps in the Academy sets The price paid for these was $110. From the general sale of duplicates the Academy has realized $165.

At the Stated Meeting of October 11, 1939, the Corresponding Secretary. read an excerpt from the will of the late Arthur E. Kennelly, by the terms of which the Academy was accorded the choice of such volumes from his scientific library as might remain after the fulfillment of certain other bequests. These items have all been inspected and several volumes and pamphlets selected.

With the approval of the Council of the Academy and of the Director of the Massachusetts Historical Society, The Academy's loan of its single volume (1759–60) of the *Boston Post-Boy* was transferred from the Historical Society (there a duplicate) to fill a gap in the newspaper files of the American Antiquarian Society. In requesting this transfer, the Director of the latter society has further proposed the permanent exchange for this item of certain scientific material to be later submitted for approval.

A preliminary survey has been made of the stacks relative to the need for oiling, repair or re-binding of the older volumes. In the absence of appropriation for this purpose it is proposed to spread the work over a time sufficient to place it within current resources

The appropriation for the year ending March 31, 1943, was $3000, and the expenditure was as follows

Salaries	$2,048 00
Purchase of books and periodicals	299 93
Binding	227 65
Total	$2,575 58

Respectfully submitted,
FREDERICK H PRATT, *Librarian*

May 12, 1943

Report of the Rumford Committee

Some weeks ago, the chairman of this Committee wrote to thirteen recent recipients of Rumford grants From four no replies have as yet been received. Of the remaining nine, five report progress and two complete cessation of the research owing to the war One, for a like reason, suggests the return of the Rumford grant. By one the statement is made that an instrument has been built but that its test has been indefinitely postponed because of war conditions

A meeting of the Rumford Committee was held January 11, 1943. As there were no applications for grants, the sole topic under discussion was the nomination of the Rumford medalist for 1943. Charles Edward Kenneth Mees was chosen by the five members of the Committee who were present. This nomination was later made unanimous by letters received from the two absentees.

During March a confirmation of this nomination, as required by the statutes, was obtained. The vote was again unanimous

The Committee, therefore, presented his name to the Academy requesting its approval of the nomination, the medals to be awarded "For his contributions to the science of photography."

Respectfully submitted,

NORTON A. KENT, *Chairman*

May 12, 1943.

REPORT OF THE CYRUS M. WARREN COMMITTEE

The Committee had available for grants during the fiscal year 1942–43 the sum of $900 From this amount the following grants totalling $700 have been made

To Professor F F Nord of Fordham University, New York City, a grant of $300 for the purchase of some rare sugars for use in continuing research in the field of enzyme reaction

To Dr. Carl C Smith of the University of Cincinnati, Cincinnati, Ohio, a grant of $400 for materials to be used in the investigation of the chemical properties of angiotonin.

The balance of $200 has been added to the appropriation for the coming year, 1943–44

A communication was received in May 1942 from Professor Arthur F Scott reporting on work undertaken with the aid of a grant in 1938 Brief reports were received from Professor J W McBain and Dr. Philip Pizzolato in regard to grants received in 1941 Dr C C Smith has reported good progress on his work on the chemical properties of angiotonin.

Reprints have been received on work carried out with the assistance of grants, as follows

Professor E. C Gilbert "The Apparent Energy of the N-N Bond as Calculated from Heats of Combustion" J. Am Chem. Soc *24*, 2369 (1942)

Professor Paul L Kirk. "Microscopy of the Amino Acids and Their Compounds" Ind and Eng Chem *13*, 587 (1941)

Professor G Krotkov Report and reprints on "Diurnal Changes in the Carbohydrates of Wheat Leaves" Can. Jour. of Research, *21*, 26 (1943).

Professor F. F. Nord. "Essential Steps in the Enzymatic Breakdown of Hexoses and Pentoses" Archives of Biochemistry, *1*, 143 (1942).

The resignation during the past year of two members of the Committee is reported: that of Professor Reid Hunt and Professor Tenney L. Davis

Respectfully submitted,

FREDERICK G KEYES, *Chairman*

May 12, 1943

REPORT OF THE COMMITTEE OF PUBLICATION

The Committee held one meeting during the year on October 4, 1942 Other business was transacted by correspondence which was necessitated by the absence of the Chairman in Washington

During the year the following numbers of the *Proceedings* were published Vol 74, No. 14 Records of meetings List of Members Statutes. Vol 75, No 1 Whitehead, A. N. and others. Papers on post-war problems At the present time the following papers are in proof

1 F M Carpenter The Lower Permian Insects of Kansas. Part 9

2 Tenney L Davis and Chao Yun-Ts'ung: Chao Hsueh-Min's Outline of Pyrotechnics

3 D L Augustine Some Factors in the Defense Mechanism against reinfection with *Trypanosoma Lewisi*

A couple of articles were submitted by persons not members of the Academy which were referred to readers in the respective fields, and declined upon receipt of their reports No other material is at present in the hands of the Editor for publication

Professor and Mrs Lake have been actively at work on the Index to *Dated Greek Manuscripts* Six of the main rubrics in this have been prepared by them and checked by the Editor with the assistance of Drs Paul J Alexander and Milton V Anastos, Junior Fellows at Dumbarton Oaks The remaining indices are expected to be finished shortly Owing to illness the Editor has been unable to make arrangements with the Waverly Press for the transfer of the bulk of the remainders of the publication to Boston, but hopes to do so before he leaves Washington in June.

Professor Hatch has been working on the indices to his *Album of Dated Syriac Manuscripts*, and the major part of these have been prepared and sent on to the printer.

The Committee wishes to go on record with an

expression of their deep regret at the death of their fellow member, Professor Joseph H Beale, on January 20, 1943. His collaboration in recent years had been impeded by illness, but his interest remained none the less unflagging and his sound counsel was of great help in various problems which arose

Respectfully submitted,
ROBERT P. BLAKE, *Chairman*

May 12, 1943

REPORT OF THE HOUSE COMMITTEE

During the year ending March 31, 1943, the House Committee had at its disposal funds amounting to $2,195, made up as follows

Appropriation for 1942–43	$2,000
Received from other societies for the use of rooms	195
Total	$2,195

The expenditures amounted to $2,754 46 Of this the sum of $2,543 59 was spent for routine expenses and $210 87 for upkeep and equipment

Meetings have been held as follows

The Academy	8
Archæological Institute of America, Boston Society	2
Boston Surgical Society	3
New England Botanical Club	9
Total.	22

The Council Chamber has been used for Academy Council and Committee meetings, and also by the Trustees of the Children's Museum and the New England Farm and Garden Association

A detailed list of expenditures follows

Janitor	$951 00
Electricity · Light	205 01
Power	68 51
Fuel	966 35
Elevator service and repairs	117.96
Telephone	124 47
Gas	50 19
Water	40 48
Upkeep and equipment	210 87
Janitor's supplies and sundries	19 62
Total	$2,754 46

Appended are the revised "Rules for the use of the House," adopted by the Council in May 1942

RULES FOR THE USE OF THE HOUSE

(Adopted by the Council, May 13, 1942)

PREAMBLE

The Council reserves the right to grant permission to or withhold permission from any organization which may seek to use the House for regular meetings or for more than one meeting in any one calendar year

RULES

1 The House of the Academy shall be available for the use of Fellows of the Academy at all reasonable hours.

2 Except as otherwise provided, the privilege of using the House of the Academy shall be enjoyed by Fellows only, who shall, however, be permitted to bring guests with them to a number not exceeding twenty.

3 Fellows introducing guests shall be responsible for any injury caused by them to the property of the Academy

4. Fellows or organizations introduced by them may use the Committee Room and the Reception Room on the ground floor and also the Assembly Hall and the Reading Room For the use of the rooms on the ground floor no charge shall be made. For the use of the Assembly Hall a charge of $10 will be made for each occasion, for the Reading Room there will be a charge of $15 if no refreshments are served, or $20, if there are refreshments An additional charge of $5 will be made for each hour or fraction of an hour during which the rooms are occupied after 11 P M The House Committee is authorized, however, to reduce the charges for small groups.

5 A visitors' book shall be kept in such place as the House Committee may determine, in which the names of Fellows using the House and the names of their guests, or organizations they introduce, shall be entered

6 Fellows, or organizations introduced by them, desiring to use either of the two large rooms for a meeting shall make application to the Assistant Librarian not less than one week in advance of the time at which the meetings is to be held.

7 The privileges of the House shall be limited to Fellows and their guests and to learned and cultural societies introduced by Fellows, ap-

proved by the House Committee, and endorsed by the Council. Societies not on the approved list should make written application to the Assistant Librarian at least two weeks in advance of the proposed meeting, and in any event sufficiently in advance to permit of action by the Council.

Respectfully submitted,
E F LANGLEY, *Chairman*

May 12, 1943.

Mr. Edmund A. Whitman spoke of the need of greater maintenance expenditure, particularly on the heating and ventilating system, which is obsolete and in poor condition. It was *Voted*, that the problem be referred to the Policy Committee, with the suggestion that the desirability of increasing the annual dues be considered.

A motion was made that the annual dues for Fellows resident within the fifty mile radius be set at ten dollars for the year 1943–44. Mr. Whitman proposed to postpone action on dues until the report of the Policy Committee After brief discussion the amendment was withdrawn and the original motion was carried

On the recommendation of the Rumford Committee it was *Voted*, to award the Rumford Medals to Charles Edward Kenneth Mees for his contributions to the science of photography.

The following officers and committees were elected for the coming year

HARLOW SHAPLEY, *President*
PERCY W BRIDGMAN, *Vice-President for Class I*
S. BURT WOLBACH, *Vice-President for Class II*
SIDNEY B FAY, *Vice-President for Class III*
FRED N ROBINSON, *Vice-President for Class IV*
ABBOTT P USHER, *Corresponding Secretary*
HUDSON HOAGLAND, *Recording Secretary*
HORACE S FORD, *Treasurer*
FREDERICK H PRATT, *Librarian*
ROBERT P BLAKE, *Editor*

Councillors for Four Years:

JOHN M. LESSELLS, of Class I
CHARLES A WEATHERBY, of Class II
ROBERT G CALDWELL, of Class III
KENNETH J. CONANT, of Class IV

Councillor for Three Years:

CALVERT MAGRUDER, of Class III

Councillor for Two Years:

DONALD S. TUCKER, of Class III

Committee on Policy and Resources:

ROBERT G DODGE, *Member for Five Years*

Finance Committee

JEROME C. HUNSAKER — JOHN F. EBERSOLE
RALPH E FREEMAN — HENRY P. KENDALL

Rumford Committee:

NORTON A KENT, *Chairman*

PERCY W. BRIDGMAN — GEORGE W. PIERCE
HARRY M GOODWIN — GEORGE R. HARRISON
HARLOW SHAPLEY — ROBERT B. LINDSAY

C. M Warren Committee.

FREDERICK G KEYES, *Chairman*

GREGORY P BAXTER — GRINNELL JONES
WALTER L JENNINGS — AVERY A. MORTON
CHARLES A KRAUS — WALTER C. SCHUMB

Committee of Publication

ROBERT P. BLAKE, *Chairman*

EDWIN C KEMBLE, of Class I
RALPH H. WETMORE, of Class II
ARTHUR H. COLE, of Class III
ROBERT P CASEY, of Class IV

Committee on the Library.

FREDERICK H PRATT, *Chairman*

RAYMOND C. ARCHIBALD, of Class I
THOMAS BARBOUR, of Class II
FRANCIS N. BALCH, of Class III
HENRY B. WASHBURN, of Class IV

Auditing Committee:

ERWIN H. SCHELL — ALEXANDER FORBES

House Committee:

ERNEST F. LANGLEY, *Chairman*

H. ADDINGTON BRUCE — ROBERT P. BIGELOW
WALTER E. CLARK

Committee on Biographical Notices:

Three Years:

RAYMOND C. ARCHIBALD — SAMUEL E. MORISON

Two Years

AUSTIN W. SCOTT

Committee on Meetings:

THE PRESIDENT

THE RECORDING SECRETARY

LEONARD CARMICHAEL	GEORGE SCATCHARD
SAMUEL H. CROSS	FREDERICK K. MORRIS

Three communications were then presented:

George Sarton: "Copernicus."

Fred L. Whipple "The Solar System."

Bart J. Bok: "The Milky Way and the Metagalaxy."

Some original editions of the works of Copernicus, loaned by the Harvard College Library, were on exhibition in the office.

The meeting was dissolved at 10 25 P M

One Thousand Two Hundred and Eighty-eighth Meeting

OCTOBER 13, 1943—STATED MEETING

The Academy met at its House at 8 20 P M

The President in the Chair.

There were present fifty-two Fellows and forty-three guests.

The records of the meeting of May 12 were read and approved.

The Corresponding Secretary reported the receipt of letters accepting Fellowship from the following. Leonard Bacon, Arlie Vernon Bock, Augusta Fox Bronner (Mrs. William Healy), Willa Cather, Ada Louise Comstock (Mrs. Wallace Notestein), David Bruce Dill, Angus Dun, Philipp Frank, Hugh O'Neill Hencken, Chester Scott Keefer, Edwin Herbert Land, Lewis Don Leet, Brenton Reid Lutz, Cecilia Payne Gaposchkin, Benjamin Morris Selekman, Jean Joseph Seznec, Donald Charles Stockbarger, Hugh Stott Taylor, Randall Thompson, Payson Sibley Wild, Jr., and Charles Edward Wyzanski, Jr.

He also reported the receipt of a letter from Henry I. Harriman resigning Fellowship, to take effect in May 1944.

The Rumford medals were then presented to Dr. Charles Edward Kenneth Mees for his contributions to the science of photography.

Dr. Mees made an address on "Sensitizing Dyes and Their Use in Photography," which was illustrated with lantern slides as well as a practical demonstration.

The meeting was dissolved at 10.00 P. M.

One Thousand Two Hundred and Eighty-ninth Meeting

NOVEMBER 10, 1943—STATED MEETING

The Academy met at its House at 8 25 P. M.

The President in the Chair.

This meeting had been designated as Ladies' Night, and there were present about 180 Fellows and guests.

The records of the meeting of October 13 were read by the Corresponding Secretary in the absence of the Recording Secretary, and approved by the Academy.

The Corresponding Secretary reported the acceptance of his election as a Fellow by Perry Gilbert Eddy Miller.

Professor Martin Wagner and Mr Hermann Herrey addressed the Academy on "The Future of Our Cities." There were lantern slide illustrations, and a special exhibition in the Reading Room, arranged by Mr Herrey

The meeting was dissolved at 10.15 P M

One Thousand Two Hundred and Ninetieth Meeting

DECEMBER 8, 1943—STATED MEETING

The Academy met at its House at 8 20 P M

The President in the Chair

There were present fifty-five Fellows and twenty-five guests

The records of the meeting of November 10 were read and approved.

The following communication was presented:

Frederick K Morris "European Topography and the Progress of the Allied Armies," illustrated with lantern slides and maps

The meeting was dissolved at 9 45 P M

One Thousand Two Hundred and Ninety-first Meeting

JANUARY 12, 1944—STATED MEETING

The Academy met at its House at 8 28 P M.

The President in the Chair

There were present fifty-three Fellows and fifty guests

In the absence of the Recording Secretary, his duties were assumed by the Corresponding Secretary.

The records of the meeting of December 8 were read and approved.

The Corresponding Secretary reported a proposed amendment to the Statutes, which had been approved by the Council, as follows:

Chapter II, Article 1, paragraph 1, to read as follows· "The Academy shall consist of Fellows, elected from the citizens or residents of the United States of America, Fellows Emeriti, and Foreign Honorary Members. They shall be arranged in four Classes, according to the Arts and Sciences in which they are severally proficient and each Class shall be divided into four Sections, namely·"

The Academy voted to amend the Statutes as recommended by the Council

The following communications were presented

T. North Whitehead and Warren A Seavey· "How Should Post-War Germany Be Treated?"

The meeting was dissolved at 10.23 P M

One Thousand Two Hundred and Ninety-second Meeting

FEBRUARY 9, 1944—STATED MEETING

The Academy met at its House at 8 30 P M.

The President in the Chair.

There were present fifty-seven Fellows and thirty guests

The records of the meeting of January 12 were read and approved.

A letter from Boston University was read inviting the members of the Academy to attend the sessions of an Institute on Post-War Problems which the University is planning to hold in connection with its Founder's Day observance, March 11, 12 and 13

The following communication was presented·

Jerome C. Hunsaker "Aeronautical Research," illustrated with lantern slides and motion pictures.

There was also an exhibit of astronomical slides by Dr. Shapley to illustrate recent astronomical discoveries

The meeting was dissolved at ten o'clock

One Thousand Two Hundred and Ninety-third Meeting

MARCH 8, 1944—STATED MEETING

The Academy met at its House at 8.25 P M.

The President in the Chair.

There were present thirty-nine Fellows and twelve guests

The records of the meeting of February 9 were read and approved

The Corresponding Secretary reported the receipt of a letter from Bradley Dewey accepting his election to Fellowship.

On the recommendation of the Council the following appropriations were made for the ensuing year·

From the income of the General Fund, $7225, to be used as follows·

for House expenses	$2,600
for General and Meeting expenses	1,000
for Library expenses	2,625
for Treasurer's expenses	1,000
	$7,225

From the income of the Publication Funds, $2,144, to be used for publication

From the income of the Rumford Fund, $3111, to be used at the discretion of the Committee.

From the income of the C. M. Warren Fund, $870, to be used at the discretion of the Committee

The President announced the appointment of the Nominating Committee:

Dugald C. Jackson, of Class I, *Chairman*
Robert P. Bigelow, of Class II
Henry P Kendall, of Class III
William C. Greene, of Class IV

He reported the discovery, through the calculations of Mr Clemence of the U. S. Naval Observatory, that the orbit of the Earth rotates in space in accordance with the Einsteinian theory of relativity Heretofore the "advance of the longitude of the perihelion" of a planetary orbit was known for Mercury only

The following communication was presented.

John H. Williams· "Post-War Currency Stabilization."

After the address by Dean Williams the President reported on a special exhibit of a new kind of "fishing frog"—a sort of deep sea monster called *Reganichthys giganteus* nov gen. et sp, by Fellows H B. Bigelow and Thomas Barbour, who have recently procured this unusual fish from a fisherman off the Maine coast. It belongs to the group called *Ceratioids*

The meeting was dissolved at 10.15 P. M.

One Thousand Two Hundred and Ninety-fourth Meeting

APRIL 12, 1944—STATED MEETING

The Academy met at its House at 8.30 P. M.

The President in the Chair.

There were present twenty-nine Fellows and twenty-four guests.

The records of the meeting of March 8 were read and approved.

The Corresponding Secretary announced that the Council had made the following grants from the Permanent Science Fund

1. To Theodor von Brand and W Gardner Lynn, Catholic University of America, Washington, D C, for special equipment for use in investigation of metabolic rates in turtle embryos, $80

2. To Curtis L. Newcombe, Associate Professor of Biology, College of William and Mary, Williamsburg, Va, for assistance in a further study of the larval stages of *Volsella demissus*, the ribbed mussel, a source of food, $600.00

3. To Frances A Schofield, Adjunct Professor of Chemistry, Randolph Macon Woman's College, Lynchburg, Va., to provide assistance and expendable materials in a further study of glycogen forming activity of alanine isomers, $500

4. To Abraham M Shanes, Instructor in Physiology, New York University, College of Dentistry, for assistance in extending a study of bioelectric potentials, $450

The President discussed plans for Academy cooperation next year with the Institute of Religious and Social Studies, as considered earlier in the evening by the Council

The following communication was presented

Frederick Fuller Russell "The War and Public Health"

The meeting was dissolved at ten o'clock

One Thousand Two Hundred and Ninety-fifth Meeting

MAY 10, 1944—ANNUAL MEETING

The Academy met at its House at 8 25 P M

The President in the Chair.

There were present forty-eight Fellows and thirty guests.

The records of the meeting of April 12 were read and approved.

The Corresponding Secretary reported that Arturo Rosenblueth had resigned his Fellowship.

He then read the annual report of the Council.

REPORT OF THE COUNCIL

Since the last report of the Council there have been reported the deaths of thirty-three Fellows Joseph Sweetman Ames, Charles McLean Andrews, Edward Cooke Armstrong, Charles Macfie Campbell, James McKeen Cattell, Russell Henry Chittenden, Winthrop More Daniels, Charles Benedict Davenport, William Johnson Drisko, Arthur Fairbanks, Albert Bushnell Hart, Aleš Hrdlička, Douglas Wilson Johnson, Arthur Keith, Alexander George McAdie, Lee Sullivan McCollester, Edward Bennett Mathews, William Cardinal O'Connell, Robert Ezra Park, William Lyon Phelps, James Bissett Pratt, Henry Washington Prescott, Alfred Lawrence Ripley, William Emerson Ritter, Frank Schlesinger, James Brown Scott, Henry Lloyd Smyth, John Frank Stevens, John Stone Stone, Robert Spurr Weston, Joseph Ruggles Worcester, David Elbridge Worrall, Karl Young, and two Foreign Honorary Members Sir William Searle Holdsworth and Sir Aurel Stein

The following Fellows have been classified as Fellows Emeriti Edward B Hill (Mar. 8, 1944), William E Hocking (Nov. 10, 1943), Carl N Jackson (Apr 20, 1943), John L Lowes (Feb 9, 1944) and Edward K Rand (Dec 9, 1942).

Twenty-seven Fellows were elected by the Council and announced to the Academy in May 1943

The roll now includes 759 Fellows, five Fellows Emeriti, and 117 Foreign Honorary Members (not including those elected in May 1944)

The reports of the Treasurer and of the standing committees, which follow, were not read to the Academy but to the Council at its meeting preceding the Academy meeting A summary of them was, however, given by the President

REPORT OF THE TREASURER

*RECEIPTS

Academy, General			
From Investment Income	$12,747 65		
Less Income to Special Funds	10,064 66		
		$2,682 99	
Assessments and Admission Fees		4,210 00	
			$6,892 99
Amory Fund Committee			
From: Investment Income			3,155 51

* Excluding sales of securities.

Publications Committee		
From. Investment Income	$2,281 60	
Sale of Publications	787 92	
Contribution	5 00	
Lake Publication, from American Council Learned Societies	2,500 00	
		$5,574 52
Rumford Fund Committee		
From Investment Income	$3,113 50	
Return of Grant	400 00	
		3,513 50
Warren Fund Committee		
From Investment Income		925 95
Mabel S Agassiz Fund		
From Investment Income		106 40
Permanent Science Fund		
From Boston Safe Deposit and Trust Co, Trustee	$9,949 74	
Return of balance of Grant	7 72	
Investment Income	417 70	
		10,375 16
Kennelly Fund		
From Investment Income		64 00
Total Receipts		$30,608 03

*EXPENDITURES

Academy, General			
Library, Salaries	$2,036.00		
Books & Binding	651 84		
		$2,687 84	
General (Net)		1,234 32	
House (Net)		2,524 35	
Treasurer's Office		570 07	
Insurance		589 70	
			$7,606 28
Amory Fund			
Expense			53 00
Publications Committee			
General		$898 87	
Lake		267 27	
			1,166 14
Rumford Fund Committee			
Grants		$650 00	
Medal		350 04	
			1,000 04
Warren Fund Committee			
Grants			250 00
Mabel S Agassiz Fund.			
For Meetings			106 40
Permanent Science Fund.			
Grants		$1,050.00	
Expense		4.93	
			$1,054.93
Special Expense			
Recording Secretary			1.91
Total Expenditures			$11,238.70

* Excluding purchases of securities

REPORT OF THE LIBRARY COMMITTEE

During the year 1943–44, fifty-three volumes and sixteen unbound numbers of serials were borrowed by eight Fellows and nineteen libraries, and many more have been consulted at the Academy.

The number of volumes on the shelves at the time of the last report was 47,114. During the year 147 bound volumes were added, making the number now 47,261 Of this number 134 were received by gift or exchange, and 13 were purchased To these are to be added a number of unbound volumes, parts of serial publications, and pamphlets, none of which are counted as volumes until they are bound.

From the American Antiquarian Society came a generous contribution of 14 bound volumes, 89 unbound volumes or numbers of serials, and a large number of pamphlets in exchange for our single volume of the *Boston Post-Boy* (1759–60), transferred as a duplicate by its borrower, the Massachusetts Historical Society, to complete the Antiquarian Society's valuable file

The appropriation for the year ending March 31, 1944, was $2,625, the expenditures being as follows

Salaries	$2,036 00
Purchase of books and periodicals	463 84
Binding	188 00
Total	$2,687.84

For the conservation of bindings, a special appropriation has been voted by the Council. In expectation of this initial grant of $100 expert advice and service have been obtained relative to oiling and repair. Of particular concern are the leather bindings of many treasured items, such as early volumes of the *Philosophical Transactions* and books belonging to the original bequest of Governor Bowdoin, the Founder, as well as the ancient works bearing the bookplate of President John Adams and other early Fellows.

Just as our rich files of modern serials and transactions in the physical sciences should attract the investigator who appreciates convenience of reference and ease of withdrawal, so our long-since static collection of 18th and 19th-century published books should have no small appeal for the antiquary who seeks to know what the Academy in the course of its first century saw fit to collect; for, in a sense not wholly figurative, they reflect the atmosphere our learned forerunners are presumed to have breathed.

Respectfully submitted,

FREDERICK HAVEN PRATT, *Librarian*

May 10, 1944.

REPORT OF THE RUMFORD COMMITTEE

During the past Academy year, but two grants have been made by the Rumford Committee The first one, July 20, 1943, was made to Dr Alvin H. Nielsen of the University of Tennessee for $350 for the purchase of a rock salt prism and four pairs of rock salt windows to be used in his study of the vibration-rotation bands of certain polyatomic molecules The second grant was made on March 11, 1944, to Professor Richard H. Goodwin of the University of Rochester for $300 for the purchase of a Kleet Fluorimeter-Colorimeter and certain accessories to be used in his studies on the effect of light upon the development of pigments in plants. Both these grants were made through correspondence and personal conferences between the members of the Committee and the Chairman. Because of war conditions, no letters were sent out asking for reports of the progress being made by previous grantees

On October 13, 1943, the Rumford Medals were presented to Dr. Charles Edward Kenneth Mees for his contributions to the science of photography.

Respectfully submitted,

NORTON A. KENT, *Chairman*

May 10, 1944.

REPORT OF THE CYRUS M. WARREN COMMITTEE

The Committee had available for grants during the fiscal year 1943–44 the sum of $950, of which $750 was appropriated at the March 1943 meeting and $200 remained as a balance from the previous year, 1942–43. From this amount two grants were made totalling $400, as follows:

To Professor Thomas W. Davis of New York University, a grant of $150 for the purchase of a Lecky-Ewell type of fractionating column and accessory equipment for use in analyzing mixtures of hydrocarbons

To Doctor Walter J. Nickerson of Wheaton College, Norton, Massachusetts, a grant of $250 to defray the expense of obtaining improved manometric equipment for use in studies on cellular respiration and for reagents to be used in attempts to synthesize possible intermediate compounds in the oxidation of acetate and ethanol.

A report has been received from Professor Davis in the form of a letter in which he states that by the time he was able to place an order for a Lecky-Ewell fractionating column, it was no longer possible to obtain one. He has since then investigated the next best procedure and finds that additional funds will be needed to secure any other type of column. He is therefore holding the grant awaiting the opportunity to secure additional funds

A report from Doctor Nickerson indicates that only a small portion of his grant has been used inasmuch as he has been in the Army for some time The unused balance of his grant is being held till such time as he can resume his research, and further reports will then be submitted. Two publications have been completed and reprints will be sent as soon as they are received from the printer

Reprints have beeen received as follows, covering work assisted by grants

Professor E C. Gilbert "The Apparent Energy of the N-N Bond as Calculated from Heats of Combustion," C M. Anderson and E. C. Gilbert, J. Am Chem Soc , *24*, 2369 (1942).

Professor F. F. Nord: "On the Mechanism of Enzyme Action. Part 21. Intermediary Phases in the Enzymatic Breakdown of d, l-Alanine by Fusarium lini Bolley." John C Wirth and F. F Nord, Archives of Biochemistry, *2*, 463 (1943)

Respectfully submitted,

FREDERICK G KEYES, *Chairman*

May 10, 1944.

REPORT OF THE COMMITTEE OF PUBLICATION

The Publication Committee held one meeting on October 6, 1943, other business having been transacted by correspondence.

Dated Greek Manuscripts. Professor and Mrs Lake have been busily engaged upon the Index to the ten fascicles which have appeared and have submitted all of the thirteen indices and a large part of the prefatory material to the editor The greater part of this is now in proof, and it is hoped that the index volume can appear by the fall.

In June, 1943, the remainders of the set were transported by truck from Baltimore and stored in the Academy's House The total cost of this operation amounted to about $160 and will represent an annual saving in insurance charges of $119 40. The Waverley Press has kept a certain number of sets on hand, and the store will be replenished from time to time as sales occur.

Album of Dated Syriac Manuscripts All the material is in the hands of the printer, and all galley proof has been corrected, but there has been some delay in receiving the page proof It is hoped that this will appear shortly, and the book can then come out in the fall Arrangements have been made with the Harvard University Press to handle the sales of the publication which have been approved by the President and the Treasurer

One article by Professor S. J Barnett of the University of California at Los Angeles has been accepted and page proof is now in the Editor's hands. It is entitled "New Researches on Magnetization by Rotation and the Gyromagnetic Ratios of Ferromagnetic Substances."

A *Records* number of the Proceedings will be published this fall which will also contain the remainders of the memoirs on deceased Fellows whose publication has been perforce delayed.

Respectfully submitted,

ROBERT P. BLAKE, *Editor*

May 10, 1944

REPORT OF THE HOUSE COMMITTEE

During the year ending March 31, 1944, the House Committee has had at its disposal funds amounting to $2,450, as follows:

Appropriation for the year 1943–44	$2,200
Received from other societies for the use of rooms	250
Total	$2,450

The expenditures amounted to $2,774.35. Of this the sum of $2,415.76 was spent for the routine expenses, janitor, heat, light, telephone, etc. and $358.59 for upkeep, furnishings and equipment The most important item in the latter category was $188, paid for putting back into working order an automatic heating and ventilating control system, which was installed when the house was built, but which had not been used for a number of years. Repairs to the elevator cost $150 53.

Meetings have been held as follows:

The Academy	8
Archæological Institute of America, Boston Chapter	1
Architectural Society of M I T	1
Boston Surgical Society	2
Institute of Food Technologists	7
Lowell Institute Alumni	1
New England Botanical Club	9
Total	29

The Council Chamber has been used for the Academy Council and Committee meetings, and also by the Trustees of the Children's Museum and the New England Farm and Garden Association

A detailed list of the expenditures follows.

Janitor	$967 00
Fuel	840 38
Elevator service and repairs	222 53
Electricity. Light	192 79
Power	44 20
Telephone	137 89
Gas	53 63
Water	47 84
Upkeep, furnishings and equipment	208 06
Janitor's supplies and sundries	60 03
Total	$2,774 35

The deficit of $324 35 will be met by transfer from the General Fund.

Respectfully submitted,

ERNEST F. LANGLEY, *Chairman*

May 10, 1944.

The President announced that he had appointed a committee to cooperate with the committee of the Institute of Religious and Social Studies, consisting of E S. Brightman, *Chairman*, the President of the Academy, A. D. Nock, and the Chairman of the House Committee.

On the recommendation of the Treasurer, the Academy voted that the annual assessment for

the year 1944–1945 for resident Fellows be ten dollars.

The annual election of officers and committees resulted as follows.

Howard M. Jones, *President*
George R. Harrison, *Vice-President for Class I*
Alfred C. Lane, *Vice-President for Class II*
Ralph E. Flanders, *Vice-President for Class III*
Fred N. Robinson, *Vice-President for Class IV*
Abbott P. Usher, *Corresponding Secretary*
Hudson Hoagland, *Recording Secretary*
Horace S. Ford, *Treasurer*
Frederick H. Pratt, *Librarian*
Robert P. Blake, *Editor*

Councillors for Four Years:

Gustavus J. Esselen, of Class I
Chester S. Keefer, of Class II
Laurence L. Winship, of Class III
Warren O. Ault, of Class IV

Councillor for One Year:

Hyder E. Rollins, of Class IV

Committee on Policy and Resources

Member for Five Years and Chairman.

Harlow Shapley

Finance Committee.

Jerome C. Hunsaker	Ralph E. Freeman
Henry P. Kendall	John F. Ebersole

Rumford Committee

Norton A. Kent, *Chairman*

Percy W. Bridgman	George R. Harrison
Harry M. Goodwin	Robert B. Lindsay
Harlow Shapley	Francis O. Schmitt

C. M. Warren Committee:

Frederick G. Keyes, *Chairman*

Gregory P. Baxter	Grinnell Jones
Walter L. Jennings	Avery A. Morton
Charles A. Kraus	Walter C. Schumb

Committee of Publication:

Robert P. Blake, *Chairman, ex officio*
Edwin C. Kemble, of Class I
Ralph H. Wetmore, of Class II
Arthur H. Cole, of Class III
Robert P. Casey, of Class IV

Committee on the Library:

Frederick H. Pratt, *Chairman, ex officio*
Raymond C. Archibald, of Class I
Thomas Barbour, of Class II
Francis N. Balch, of Class III
Henry B. Washburn, of Class IV

Auditing Committee:

Erwin H. Schell	Alexander Forbes

House Committee.

Charles M. Spofford, *Chairman*

H. Addington Bruce	Robert P. Bigelow
Donald S. Tucker	

Committee on Biographical Notices:

Three Years

Abbott P. Usher, *Chairman*
Leigh Hoadley

Committee on Meetings

The President
The Recording Secretary

Leonard Carmichael	Jerome D. Greene
Abbott P. Usher	Frederick K. Morris

The Corresponding Secretary announced that the following had been elected members of the Academy

FELLOWS

Class I

Section 1. Saunders MacLane, Cambridge
John von Neumann, Princeton, N. J.
Section 2. Ronold Wyeth Percival King, Winchester
Section 3. Isadore Amdur, Cambridge
Linus Carl Pauling, Pasadena, Cal
Edgar Bright Wilson, Jr., Cambridge
Section 4. Arthur Robert von Hippel, Weston
Richard von Mises, Cambridge
Karl Terzaghi, Winchester

Class II

Section 1. Columbus O'Donnell Iselin, II, Woods Hole
Harald Ulrik Sverdrup, La Jolla, Cal.
Section 2. Paul Rupert Gast, Petersham
Hugh Miller Raup, Jamaica Plain
Albert Charles Smith, Jamaica Plain
Section 3. Eugene Markley Landis, Brookline

Section 4. Maxwell Finland, Boston
William Malamud, Worcester
George Widmer Thorn, Cambridge

CLASS III

Section 2. Vera Micheles Dean, New York, N. Y.
Carl Joachim Friedrich, Concord
Sarah Wambaugh, Cambridge
Section 3. Douglass Vincent Brown, Brookline
Section 4 Adolf Augustus Berle, Jr., Washington, D. C.
Raymond Blaine Fosdick, New York, N. Y
Ernest Martin Hopkins, Hanover, N H
James Rhyne Killian, Jr., Wellesley Hills
Beardsley Ruml, New York, N Y.
Leverett Saltonstall, Chestnut Hill
Charles Edward Wilson, New York, N Y

CLASS IV

Section 2. William Bell Dinsmoor, New York, N. Y.
Clyde Kay Maben Kluckhohn, Cambridge
Ambrose Lansing, New York, N. Y
Section 3. Henry Grattan Doyle, Washington, D. C.
Elias Avery Lowe, Princeton, N. J.
La Rue Van Hook, New York, N. Y.
Section 4 Walter Gropius, Lincoln
Charles Rufus Morey, Princeton, N. J.
Karl Vietor, Cambridge
Herbert Eustis Winlock, New York, N Y

FOREIGN HONORARY MEMBERS

CLASS II

Section 1 Ezequiel Ordoñez, Mexico, D. F.

CLASS III

Section 1. Victor Andrés Belaúnde, Lima, Peru
Section 3 Daniel Cosío Villegas, Mexico, D. F.

CLASS IV

Section 3. Amado Alonso, Buenos Aires, Argentina

The following communication was presented· Sarah Wambaugh. "The Place of the Small State in Organization for Peace."

Dr. Francis O. Schmitt exhibited a selection of electron microscope pictures of biological specimens

The meeting was dissolved at 10.35 P. M.

BIOGRAPHICAL NOTICES

FRANCIS GREENLEAF ALLINSON (1856–1931)

Fellow in Class III, Section 2, 1914

Francis Greenleaf Allinson was born at Burlington, N. J., Dec. 16, 1856 and died at his summer home, Hancock Point, Me., June 23, 1931. He was a son of the Quakers, William James and Rebecca Webb (Hinchman) Allinson, and a great-great-grandson of Joseph Allinson who came from Yorkshire, England to Burlington in 1718. His father, a drug merchant and for many years the editor of *The Friends Review* of Philadelphia, was a close personal friend of the poet Whittier in anti-slavery times, and the son Francis was given the poet's middle name. Less than six months later Whittier published a poem, "My namesake "[1]

Francis entered Haverford College and graduated A.B in 1876 and A M. in 1879. After a year at Harvard he received the degree of A.B there also in 1877. He then had the wonderful experience of spending three years as fellow in Greek at The Johns Hopkins University in part of the most glorious period of its history, and became a pupil of the great Gildersleeve. When the University was opened in 1876 President Gilman assigned Gildersleeve to an empty room and told him to "radiate " The effect of this radiation in Allinson's case was magical, and after a distinguished career he was naturally selected as Gildersleeve's biographer by the editors of the *Dictionary of American Biography*. He received his Ph D. at Johns Hopkins in 1880 for a dissertation "On Ionic forms in the second century" (*Amer. Jl Philol*, v. 7).

He was successively assistant professor of Latin and Greek at Haverford College (1880–82), headmaster of classics at the University School for Boys, Baltimore, Md. (1882–91), and associate professor of Greek and Latin at Williams College (1892–95) In 1895 he joined the faculty of Brown University as associate professor of Greek and classical philology. He became the professor of classical philology (1898–1915), and was professor of Greek literature and history from 1915 until his retirement as professor emeritus in 1928 During 1910–11 he represented Brown University as the professor at the American School of Classical Studies in Athens, and for many years he served as a member of the managing committee of that School. During the last five months of 1917 he was Sather lecturer on classical literature at the University of California.

Allinson's many articles, biographical sketches and reviews are to be found in such periodicals as *American Journal of Philology, Classical Journal, Classical Philology, Classical Weekly, Education, Transactions and Proceedings* of the American Philological Association, *Harvard Studies in Classical Philology, The Review* (N Y), *Nation, Century Magazine, The Brown Magazine, Brown Alumni Monthly, Haverfordian*, and *Quaker Alumnus*, Philadelphia Allinson was an ideal writer of reviews, where his wide knowledge and keen sense of humor were often in evidence. He contributed also to the *Studies in Honor of Basil Lanneau Gildersleeve* (1902), to the *Goodwin Volume of Harvard Studies in Classical Philology* (1901), and the articles on "Albert Harkness" and "John Larkin Lincoln," to the *Dictionary of National Biography*

His first book was *Rules of Latin Syntax* (Baltimore, 1883) and his second book, *Greek Prose Composition*, went through three editions (Boston, 1890–95) Allinson was long a student and lover of the witty Lucian and brought out a school edition (1905) of *Selections* from his writings Then in 1926 his *Lucian—Satirist and Artist* appeared in "Our Debt to Greece and Rome" series Admirable features, as well as defects, in this work have been set forth by L. E. Lord (*Classical Journal*, v. 23, 1928, p 548–549) and by A. S. Owen (*Classical Review*, v. 41, 1927, p. 179).

Perhaps Allinson's most important contribution to scholarship was his edition of the principal fragments of *Menander* for the Loeb Classical Library (1921) It summarized all of his work in this field. No other classical author was previously so inaccessible to the student of Roman comedy in an English edition as Menander, but here the modern problem was not only to prepare

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[1] This appeared in *Harpers Weekly*, May 13, 1857, vol 1, p 323, there are 42 stanzas with four lines in each stanza. *The Friends Review* for June 27, 1857, contains "To J Greenleaf Whittier. The namesake's response," signed "Greenleaf " This was unquestionably written by the father.

a definitive text, but also translation and commentary. The result was a worthy addition to the Loeb series by one of the best living authorities on Menander.

Professor Allinson was twice married,—first, in 1885, to Mary Irwin Carey of Baltimore, who died in 1901 leaving one daughter, and second, in 1905, to Anne Crosby, daughter of Lucilius Alonzo Emery, chief justice of the supreme court of the state of Maine. The second Mrs. Allinson was also a classical scholar and a remarkable woman of great intellectual brilliance. She was dean of women and assistant professor of classical philology at the University of Wisconsin 1892–1900 and dean of the Women's College at Brown University 1900–1905 Besides being the author of a number of books and articles of her own, she collaborated with her husband in *Greek Lands and Letters* (1909) of which there were later editions in 1922 and 1931 They edited also an edition of John Conington's English translation of Virgil's Aeneid (Chicago, 1916, 1923).

Their home was a recognized center of friendly discussion and intellectual interchange, and their brilliant and witty conversation was a source of exhilaration to every visitor. Professor Allinson possessed something of the delicacy of the Hellenic attitude which seemed to influence his manner and way of thinking He was ever courteous and considerate though he could be vehement in his criticisms of policies and tendencies he did not approve. He wrote of Gildersleeve, "As in his more personal teaching, where a 'mistake' was a 'crime,' so in the wider sweep of his seminary courses an ineluctable exactitude prevailed. No vagueness was acceptable." Every word of this might also be applied to Allinson He was a very inspiring teacher. He taught his students to form definite opinions. Enthusiasm, great stores of learning at instant command, humor, delight in the specially happy phrase of a translation, and breadth of view which recognized the great importance of fields of knowledge unrelated to his own, made every class-room meeting stimulating.

He was much sought as a lecturer and as a reader of his translations from the Greek. For example, at Brown University in 1917 his subjects were, "Aeschylus: seven against Thebes,—national patriotism", "Plato Republic, the universal commonwealth", "The Greek anthology: selected epigrams,—from Greek democracy to Byzantine imperialism." Similarly in 1920, "Selections from Lucian, films from a second century kodak", "The Eumenides—The construction of conscience." Of his many other lectures we may refer simply to his Phi Beta Kappa oration on "Daedalus" at Smith College in 1928.

Among other expressions of recognition of his eminence, we may note his election as a fellow of this Academy (1914), as president of the American Philological Association (1921–22), his repeated election as Trustee of the Providence Public Library (1904–31), his receipt of honorary degrees, Litt D conferred by the University of Wisconsin (1922) and also by Trinity College (1922), and LL D. by Haverford College (1931).

He was a graceful writer and a sparkling satirist, fastidious in his criticism and generous in his praise Unassuming by instinct Professor Allinson left his mark of sincerity and genuineness upon a broad circle of acquaintances One may appropriately close with Allinson's own translation of six lines of Schiller's "Die Ideale" rehearsing the two elements, "friendship" and "creative work" which had given most value to the poet's life, as well as to his own. "The closing lines," writes Allinson, "have always seemed to me the perfect picture of the scholar's ideal, however conscious he may be that he falls short of the goal "

Creative work that resteth never
That ne'er destroys, but through *slow* ages
Still adding grain to grain, forever
Eternity's vast structure rears
Yet from the debt on Time's great pages
Doth cancel minutes, days and years.

R. C. Archibald

CHARLES BARROIS (1851–1939)

Foreign Honorary Member in Class II, Section I (1915) 1919

Professor Charles Barrois, of Lille, for half a century eminent among the geologists of Europe, was one of the ablest and most illustrious investigators and teachers in the field of the earth sciences that France has produced.

Born at Lille, on April 21, 1851, into one of the great industrial families of northern France, Charles Barrois chose to use his energy and talent in scientific work, rather than in business. When twenty years of age he decided to become a geologist. A few years later he became assistant to Professor Jules Gosselet in the Department of Geology which had just been organized at the University of Lille He soon began to publish on a variety of geological and paleontological subjects. In one of his earlier papers, for which he was awarded a doctorate of science at the Sorbonne, he made a very useful correlation of the Upper Cretaceous faunal zones of England and Ireland with those of France which has stood the test of time and helped to establish his reputation for careful and thorough stratigraphic work.

During his long and active life more than 150 papers, some of them memoirs of great scientific value, flowed from his pen. They dealt with many branches of the earth sciences—invertebrate and vertebrate paleontology, Cambrian to Quaternary stratigraphy, structural and areal geology, petrology, seismology, and economic geology. Most of them were based on studies of the rocks and fossils of France, but some of the most important of them related to the stratigraphy and paleontology of Spain, and Great Britain Many of them were descriptions of the geology of areas covered by sheets of the Carte Géologique de la France, which were prepared for, and published by, the Geological Survey of France The majority of these areas were in Normandy and Brittany, and some of Barrois' most important contributions to science related to the geology and paleontology of those provinces.

But Charles Barrois will be best remembered for his studies of the coal fields of the Nord and of Pas-de-Calais and for the great collection of rocks and fossils from the Carboniferous strata of those regions, and of models showing the geological structure of those beds, which he placed in the Musée Houiller of the University of Lille. He had been largely responsible for the establishment of this museum in 1908 In 1902 he had been made head of the Department of Geology of the University, and the museum will remain as a monument to the work which he did to make that department known throughout the world as a center for teaching and research on the geology and paleontology of coal.

The high quality of Barrois' scientific work was widely recognized by his contemporaries. He was a Commander of the Legion of Honor, a member of the Academy of Sciences of Paris and at one time its president, a foreign member of the Royal Society of London and of the Royal Society of Edinburgh, a member of the Pontifical Academy, a foreign fellow of the Geological Society of London, a foreign correspondent of the Geological Society of America and a foreign member of societies and academies in Belgium, Germany and Spain

Professor Barrois died on November fifth, 1939, at the age of ninety-one He is buried in Lille, where he labored so effectively in his chosen field for almost seventy years.

B. F. HOWELL

CHARLES VALUE CHAPIN (1856–1941)

Fellow in Class II, Section 4, 1914

Dr. Charles Value Chapin, who was born in Providence, Rhode Island, on January 17, 1856, died at his home on Keene Street, Providence, on January 31, 1941, at the age of 85, having been in failing health for about two years.

During his forty-eight years as Superintendent of Health in Providence, Dr. Chapin revolutionized theories of public hygiene and made many contributions to the field of medical knowledge which gained him worldwide renown. Dr Chapin's theory of "the person, not the thing," advanced early in his career here, combatted the then generally accepted theory that germs of disease were communicated from one person to another through the air and in various ways. He expressed the belief that disease was mostly communicated through personal contact, and that if a person who cared for another having a communicable disease were to wash his hands thoroughly after coming in contact with the patient or touching anything handled by the diseased person, he would run but little danger. When this theory was first publicly expounded by him it was greeted with derision. The experiment was watched with interest and proved entirely successful.

Some of the accomplishments in Providence

during Dr. Chapin's administration were listed in a survey report by the American Public Health Association. It was pointed out that Providence was the first city in the United States to establish, in 1888, a municipal laboratory; it was in Providence that, in 1893, the first experiments in filtering water by mechanical filtration were made; Providence was the first city to discontinue, in 1905, fumigation as a form of terminal disinfection in the prophylaxis of contagious disease.

Dr. Chapin's outstanding contributions to the advancement of public hygiene were widely recognized during his long term of service as Superintendent of Health, and in retirement he was the recipient of many honors Dr Chapin took office when the department consisted of the head and one assistant, an ex-policeman. When he retired, he was head of a large corps of health workers and had supervised the building and development of the Providence City Hospital, the name of which was shortly changed to the Charles V. Chapin Hospital.

In 1909, Dr. Chapin, already recognized as an authority on public health work, accepted an invitation to deliver a series of lectures in the Harvard Medical School, and the treatises he there expounded were printed for wide distribution. For several years he also delivered an annual series of lectures at the Harvard-Massachusetts Institute of Technology School for Health Officers. In 1910 he published "Sources and Modes of Infection," which today is used as a textbook in medical schools. In 1913, Dr Chapin undertook for the American Medical Association a survey of "State Sanitation" throughout the United States His report of this survey submitted to and published by the Association, was declared a monumental work. In 1917 he was appointed one of a committee of ten eminent health experts by the National Red Cross War Council to advise on war relief and health work in Europe. In 1935 he was officially lauded by the hygiene section of the League of Nations for "revolutionizing the principles of disinfection following contagious diseases." In 1927 Yale University conferred upon Dr. Chapin the honorary degree of Doctor of Laws, and in 1928, in the presence of members of the National Academy of Sciences in Washington, he was presented the Marcellus Hartley medal for eminence in the application of science to the public welfare. Dr. Chapin was one of eight men in the world upon whom this honor has ever been conferred.

An award which was perhaps the greatest honor to be conferred on Dr. Chapin during his lifetime came to him in April, 1930, when the American Public Health Association presented him with the Sedgwick Medal, the greatest tribute within the gift of his contemporaries throughout all of North America.

In 1935, on the 59th anniversary of his graduation from Brown, the University conferred on him the Susan Colver Rosenberger Medal, the highest honor it can give an alumnus in recognition of distinguished service to humanity

In the passing of Dr. Chapin, this country has lost one of its greatest benefactors, and Providence one of its most outstanding citizens What he taught will live as the work of the highest type of public servant, having the welfare of his fellow men his first interest

ARTHUR H. RUGGLES

JAMES PYLE WICKERSHAM CRAWFORD
(1882–1939)

Fellow in Class IV, Section 3, 1938

The University of Pennsylvania's distinguished Hispanic scholar Professor James Pyle Wickersham Crawford, was born in Lancaster, Pa., February 19, 1882, died September 22, 1939

From a serious breakdown suffered in 1931 he had rallied—thanks to his invincible courage and the devoted care of his wife—to a degree that enabled him to carry on a large part of his University work His death occurred shortly after a homeward voyage from Europe at the outbreak of the war.

After graduating from the University of Pennsylvania at twenty, he spent two years in its Graduate School, guided in his chosen field of Spanish studies by the late eminent Professor Hugo Albert Rennert. Two further years he spent in study at the Universities of Madrid, Freiburg and Grenoble. On receiving the Ph.D. degree, he started his long and honorable career at his own University.

In him were happily united the sound scholar

and the dynamic teacher He won the respect of his students for his learning and critical insight, their admiration for the joyous energy of his personality, and their gratitude for his helpfulness.

To the field of Spanish drama and poetry of the sixteenth century he contributed these outstanding books: *Life and Works of Cristóbal Suárez de Figueroa, The Spanish Pastoral Drama,* and *Spanish Drama before Lope de Vega;* all of these published by the University of Pennsylvania; the first also appeared in a Spanish translation published at Valladolid.

The list of his articles and reviews in learned periodicals here and abroad is extensive, besides which he prepared valuable school editions of various Spanish works of fiction, as well as widely-used school text-books of Spanish grammar and composition. As an editor, he was in charge of *The Modern Language Journal* from 1922 to 1926, and from 1933 to his death he was editor of the quarterly *Hispanic Review,* the publication of which by the University of Pennsylvania Press he had planned in 1930. The January 1940 number of this periodical contains a complete, classified bibliography of Professor Crawford's writings

Besides the American Academy of Arts and Sciences, Professor Crawford was a member of the following societies: Phi Beta Kappa, the American Association of Teachers of Spanish, the Modern Language Association of America, the Linguistic Society of America, the American Philosophical Society, and the Medieval Academy of America, and a corresponding member of the Real Academia Española, the Hispanic Society of America, the Real Academia Hispano-Americana de Ciencias y Artes de Cádiz, and the Academia de Bellas Artes de Valladolid

Franklin and Marshall College conferred upon him the honorary degree of Doctor of Letters in 1925.

GEORGE BENSON WESTON

WILLIAM SUDDARDS FRANKLIN (1863–1930)

Fellow in Class I, Section 2, 1919

William Suddards Franklin was born at Geary City, Kansas, October 27, 1863, son of Thomas Henry and Cynthia Ann (Curtis) Franklin. The father was born in Philadelphia to Edward Franklin from the east shore of Maryland and Mary (Franklin) Franklin from New England; the mother was a Missouri girl. The father, a graduate of Central High School in Philadelphia, went to Kansas in 1857 to build and operate a sawmill for a Philadelphia firm. There were five children: Edward Curtis (who became professor of chemistry, Leland Stanford Jr., University, and member of the National Academy of Sciences and of this Academy), William and his twin sister Nellie, Joseph who died at 15, and Thomas Z (with Aetna Life Insurance Co., Hartford), a high degree of ability marked them all, with William probably the ablest.

W S Franklin was graduated B S at the University of Kansas in 1887 and M.S. there in 1888. He so early showed exceptional ability in mathematics and physics that he became an instructor in physics in his second undergraduate year; following his graduation he served three years as assistant professor of physics For the year 1890–91 he studied at the University of Berlin with Helmholz, Planck and Kundt, and during 1891–92 was Morgan Fellow at Harvard University While professor of physics and electrical engineering at Iowa State College 1892–97, he studied further at Cornell University from which he received the degree Sc D in 1901. He was professor of physics and electrical engineering at Lehigh University 1897–1903 and professor of physics 1903–15, subsequently he was lecturer in physics at Columbia University (1915–17), lecturer and professor of physics at Massachusetts Institute of Technology (1917–29), lecturer at Harvard (1917–25), and visiting professor at Rollins College from 1929 till his death

On May 14, 1888 Franklin married Hattie Fenn (daughter of Franklin Stiles) Titus of Washington, Conn They had two sons, Curtis Titus and Vernon Lyman Kellogg Franklin All these members of his family survived him. He died in Wilmington, N C, on June 6, 1930, as a result of an automobile accident

In addition to his life of teaching Franklin served engagements as consulting engineer to the General Electric Co and other companies, and was engaged at the Bureau of Standards on war work. He had a national reputation as an elec-

trical engineer and was an authority on alternating currents. He read constantly and widely in all branches of physics and engineering and was sympathetic to the newer theories of relativity and of quanta which came along during his maturer years Though many thought of him as only an undergraduate teacher and writer of text books he had a considerable record of published research, great originality of mind, and his advice was always available to and highly valued by graduate students and younger scientists. The especial force of Franklin whether as productive physicist or engineer, as author of text books, or as teacher lay in his sense of reality—the world was vividly real to him and he wanted it to be so to others.

It was probably this keen sense of reality and vivid interest in persons, as well as in ideas and in things, which led him to slacken his scientific research in favor of teaching and research in teaching and further led led him to find an avocation in child welfare and in the development of outdoor recreational facilities for the young. One who had so keenly enjoyed the fishing, swimming, tramping in Western plain and mountain wished to see that so much as might should be provided for those who spent their youth in spaces less open It was in connection with these interests that he wrote "Bill's School and Mine" and "Tramp Trips through the Rockies," and probably no scientific honor that could have come to him would have so touched him as did Bethlehem's action in naming Franklin Park in his honor.

Franklin was fellow of the American Association for the Advancement of Science (former vice-president and chairman of the section of physics), member of the American Institute of Electrical Engineers, American Physical Society, Kansas Academy of Sciences (honorary), Iowa Academy of Sciences (former president), Phi Beta Kappa, Sigma Xi, Tau Beta Pi and Phi Delta Theta He received (posthumously) the first award by the American Association of Physics Teachers of its medal in recognition of preëminent contributions to the teaching of physics. He was elected Fellow of this Academy in 1919, member of the Council 1921–25, Chairman of the publication Committee and Editor, 1925–39. The generosity with which he gave his time to the Academy as an officer and the liveliness of his discussion of papers presented at the meetings merit especial mention here. He was always and in every capacity so thoroughly generous, alive and vivid!

A bibliography, undoubtedly incomplete though compiled from many sources, is appended.

EDWIN B. WILSON

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LOUIS JOHN GILLESPIE
(1886–1941)

Fellow in Class I, Section 3, 1928

Louis John Gillespie* was distinguished for the great variety of fields in which he was interested and in which he made valuable contributions, and for the breadth of vision he derived from his diverse interests. He was born at Hillsboro Bridge, New Hampshire, on June 10, 1886, the son of John Joseph and Luella (Walker) Gillespie.

In 1911 he married Elsie Vaughn Jenney. She and their two children, Louis J. Gillespie and Marguerite Gillespie Greenlie, survive him.

He received his education in the schools of Manchester, New Hampshire, and at Brown University, where he specialized in physics and chemistry as an undergraduate, and in biology as a graduate student. He received the Ph.B. degree from Brown in 1908 and the M.A. and Ph.D. degrees in 1911. During part of his graduate course he was Assistant to Professor Barus in the Physics Department.

From 1911 to 1913 he held a Fellowship in Biology in the Hospital of the Rockefeller Institute for Medical Research. In 1913 he became Bacteriologist with the New York City Board of Health, and subsequently Scientist in the Bureau of Soils of the United States Department of Agriculture in Washington. In 1915 he became Biochemist in the Bureau of Plant Industry of that Department. He was Professor of Physical

* See the sketch by J. A. Beattie, Nucleus, *18*, 205 (1941).

Chemistry at Syracuse University during 1919 and 1920. In 1920 he came to the Massachusetts Institute of Technology as Assistant Professor of Physico-Chemical Research. He advanced to Associate Professor in 1926 and to Professor in 1931.

He was born with a keen ear, absolute pitch, facility with musical instruments and a great love for music. As a boy he learned to play the violin, piano, trumpet and trombone, and he earned most of his college expenses by the use of his musical ability. Although he never played professionally after graduation, he was actively interested in music all his life. He learned to play the cello and the viola, and for a short time he played the cello in one orchestra, the viola in another, and the trombone in a third. He composed a score of short piano pieces, two string quartets and a symphony. He was also greatly interested in the physics of music, especially as it related to the tone color and quality of musical instruments, and to those musical intervals which give esthetic satisfaction.

His first publications, from Brown University, dealt with the application of precise physico-chemical measurements to biological problems. At the Rockefeller Institute he shared in the pioneer work of characterizing the different types of pneumococci At the Department of Agriculture he returned to the application of physico-chemical technique and reasoning to biology in the development of methods for measuring hydrogen-ion potentials and reducing potentials, particularly in soils. He pioneered in educating the biological and agricultural chemists to distinguish between these two potentials, and between them and the quantities of acid and reducing agents.

At the Massachusetts Institute of Technology his biological interests were continued in a course in physical chemistry for students of biology and in the text book "Physical Chemistry," which he wrote for it. He also developed a graduate course in thermodynamics, which was largely an exposition of Gibbs' original papers. His research was mostly in thermodynamics, including studies of calorimetry, solid-gas equilibria, and the effect of pressure on chemical equilibria in non-ideal gases. His research, like his music, was strongly individualistic. Neither the problem chosen nor the methods of attack followed the fashion, but both reflected the breadth of his vision. His studies of thermal diffusion were very timely on account of the widespread interest in the separation of isotopes by this method. Yet his own chief interest was in solving the difficulties which he had brought to light before the subject became popular, his approach was unusual, and his publication was unhurried. His researches are published in more than fifty scientific articles.

Important as were the direct results of these varied activities, the effect on his own development was perhaps fully as important. He was a teacher and a guide whose broad knowledge, wide perspective and keen judgment were always at the service of his students and colleagues. He contributed much by doing, even more by being.

GEORGE SCATCHARD

WILLIAM ARTHUR HEIDEL
(1868–1941)

Fellow in Class IV, Section 1, 1910

William Arthur Heidel was born in Burlington, Iowa, in 1868, and died in Middletown, Connecticut on January 15, 1941, in his seventy-third year. A graduate of Central Wesleyan College he proceeded for graduate instruction in the classics to the university of Berlin Here he was fortunate enough to receive the personal instruction and friendship of Professors Zeller and Diels who inspired him to undertake for his life work the study of ancient Greek philosophy After a two-year sojourn abroad, he returned to this country to complete his work for the doctorate at the University of Chicago, then still a very young university, under the guidance of Professor Shorey. It was here also that his long friendship with Professor John Dewey began One of the earliest philosophical books, in part written and wholly edited, by John Dewey, *Studies in Logical Theory*, contains an article by Professor Heidel on The Logic of the Pre-Socratic Philosophy. While it was difficult for Professor Heidel to choose between a promising career in philosophy or in the classics—Professors Shorey and Dewey simultaneously offered him teaching posts at Chicago—he finally determined to devote himself to classical studies, but with particular reference

to pre-Socratic philosophy and science It was in this field that he was to win singular distinction at home and abroad

His first teaching appointments were in the Middle West; but from 1905 on he became professor of Greek at Wesleyan University in Middletown, Connecticut, where he continued to teach until 1928, when he was appointed a Research Associate of the American Council of Learned Societies to carry on his work on the History of Greek Thought In 1938 he became Research Associate Emeritus.

Professor Heidel's carefulness in scholarship and his hostility to dogmatism kept him from hasty publication, but steadily important studies emerged from his pen that had been sometimes twenty years in the maturing Some of the more important of these studies like his Περὶ φύσεως, *A Study of the Conception of Nature Among the Pre-Socratics* and his *Hecataeus and the Egyptian Priests in the Herodotus, Book II*, as well as many other smaller studies appeared either in the Proceedings or the Memoirs of the American Academy of Arts and Sciences His scholarship was as carefully etched as was his miniature handwriting his friends came to know

While he always stressed how meager was the evidence for much we should like to know in early Greek thought, his enthusiasm for new clues and new modes of approach always carried him forward In later years it was the scientific theory and practice of the ancient Greeks, particularly of the followers of Hippocrates, that engrossed his attention It is to be hoped that some of the important material he was working on when death overtook him can be published posthumously

With all of Professor Heidel's great learning he was not a recluse the life of the nation and of the world concerned him greatly. The range and accuracy of his knowledge on many subjects unrelated to the academic life never failed to surprise his friends In late years his keen sense of justice and his great capacity for sympathy were often strained when he would hear, sometimes directly, of another great injustice done to a distinguished scholar abroad. While Professor Heidel's scholarly work was set in ancient Greece, truly his eyes surveyed the world

CORNELIUS KRUSÉ

WILLIAM CASPAR GRAUSTEIN
(1888–1941)

Fellow in Class I, Section 1, 1924

William Caspar Graustein was born in Cambridge, Mass , November 15, 1888 He graduated from Harvard, Magna cum laude, in 1910. He spent the next year in the same place doing graduate work in mathematics, his main interest then, as ever afterwards, was in the field of geometry For this reason it was entirely natural that he should spend the next two years in Bonn working with that distinguished, but highly individualistic geometer, Eduard Study This was the beginning of an intimate personal and intellectual intimacy which lasted many years, and had a most profound effect on Graustein's whole scientific career.

He took the doctor's degree, Summa cum laude, in Bonn in 1913 and returned to Harvard for a year as instructor in mathematics He was then promoted to an assistant professorship in the newly formed Rice Institute in Houston, Texas Here he joined his Cambridge friend, Griffith Conrad Evans in building up, with the warm approval of President Edgar Odell Lovett, the most advanced mathematical centre south of Mason and Dixon's line This lasted until the war

He returned to Harvard in the autumn of 1919 to help in the congenial task of rehabilitating the Division of Mathematics, which in one year had lost three of its most valuable members through death and transfer He worked mightily at this task till the day of his death, climbing steadily to the top of the academic ladder. He was chairman of the Division from 1932 to 1937, and Assistant Dean of the Faculty of Arts and Sciences from 1939 to 1941. But he served mathematics outside his own university as well. He was for many years one of the leading editors of the Transactions of the American Mathematical Society, and chairman of a very busy committee organizing a proposed International Mathematical Congress to be held in Cambridge in 1940. He was killed in a motor accident January 22, 1941.

Graustein's approach to mathematics was essentially the artistic one. He was never attracted to a new theory merely because it was

novel or bizarre. Neither did he take pleasure in extended mathematical elaborations the only apparent object of which is to show the writer's virtuosity. His object was to reach some definite mathematical truth by the most attractive road, and to state it as generally and as accurately as possible. His doctoral thesis dealt with a method of representing all points, real or complex, of a space curve, by two real surfaces of special type in a definite relation to one another In subsequent years he published other papers on complex geometry, but the method of representation suggested to him more general problems connected with mapping of one surface on another especially when the tangent planes at corresponding points are parallel The introduction of the absolute differential geometry, and tensor notation had a curious effect on him. He clearly saw the great increase in generality that came in this way, and he mastered the new technique. But he also was led to perceive resources in the older geometry that had been somewhat neglected before In particular he stressed the advantages of so called invariant methods which are independent of the more or less fortuitous choice of parameter systems for determining elements His paper, "Méthodes invariantes dans la géométrie infinitésimale des surfaces," was awarded a prize by the Belgian Academy of Sciences in 1929; an elaboration in English was delivered, by request, before the American Mathematical Society a year later and was published in their Bulletin in August 1930 The totality of his scientific papers, mostly in the field of differential geometry, amounts to some three dozen titles.

The quality which makes Graustein's papers excellent reading was manifest in his teaching, for he was a most admirable teacher, clear, painstaking and stimulating. He published three timely geometrical text-books, "Plane and Solid Analytic Geometry," with W. F Osgood, 1921, "Introduction to Higher Geometry," 1930, "Differential Geometry," 1935. But no printed page could convey the real quality of the teacher or the man.

JULIAN L. COOLIDGE

SAMUEL HENSHAW (1852–1941)

Fellow in Class II, Section 3, 1889

Samuel Henshaw was born in Boston, January 29, 1852, and died in Cambridge, February 5, 1941 Of an old Boston family he was the son of Joseph Lyman Henshaw and Jane Paine Henshaw He had a sister, Elizabeth Lyman Henshaw, who died October 24, 1926, and a brother, Joseph Putnam Bradlee Henshaw, who died October 11, 1930. Samuel Henshaw married Miss Annie Stanwood, April 28, 1886. She died March 12, 1900 Her death was a desperate blow that radically changed all his subsequent life

Henshaw went to the Chauncy Hall School, and the Boston Latin School. He did not go to college, but received an Honorary A M from Harvard in 1903.

Henshaw was short in stature; but very strong. He had wonderful eyesight so that he could read the finest print and he never wore glasses, even in his old age He had a very keen and critical mind in affairs and in his relations with men. This gave his judgment great weight with his associates. The keynotes of his character were his sensitiveness, his sense of fun, his personal integrity and his devotion to his work and his friends.

Primarily an entomologist, he had wide knowledge in other groups of animals, and his knowledge of scientific literature was both very great and very accurate This helped him greatly in his editorial work which was very extensive throughout his active years. He was gifted with a singleness of purpose and an intense application to work that is rarely equalled.

All his life interested in natural history, he became a member of the Boston Society of Natural History in 1871 In 1876, I first find record of his working on the collection of insects in the Society. From that time on, until 1891, Henshaw was working at the Boston Society as assistant to Professor Alpheus Hyatt. While insects were his primary interest, he worked on various groups of invertebrates and vertebrates as well, and assisted Professor Hyatt greatly in preparing material for his courses in the Teacher's School of Science, a department of the Lowell Institute

In 1892, Henshaw became Secretary and Librarian of the Boston Society of Natural History, which position he held until 1901, when he was succeeded by C. F. Batchelder, and a year later by Glover M Allen.

In 1891–1898, Henshaw was part-time assistant in entomology at the Museum of Comparative Zoölogy, succeeding Dr. H. A. Hagen, who had retired on account of illness From 1898–1903, he was assistant in entomology and librarian of the Museum of Comparative Zoology From 1903–1911, he was Curator of that Museum, when his title was changed to Director, and this position he held until November, 1927, when he was succeeded by Dr. Thomas Barbour From 1927, his title has been Director of the University Museums and of the Museum of Comparative Zoölogy, Emeritus

Henshaw was a Fellow of the American Academy of Arts and Sciences, member of the American Society of Naturalists, and American Society of Zoologists. He was one of the founders of the Cambridge Entomological Club, which started publishing Psyche in 1874, and for a time he edited that Journal,

While Secretary of the Boston Society of Natural History, he edited their publications and during at least a large part of his connection with the Museum of Comparative Zoology, he edited the publications of that institution As an editor, he was most painstaking, careful and exact.

When I first knew Henshaw, he lived in Mercer Circle, Cambridge, and later I became his opposite neighbor in Fayerweather Street He was essentially a gentleman of the old school, with all the refinement and courtesy that that term implies This in spite of a "crust" that often hid his finer feelings. These finer feelings were expressed in his devotion to his close friends, especially Dr. H. A Hagen, Mr Samuel H Scudder, and Dr. Henry P Walcott, notably in the years of their invalidism Among others to whom he gave his great loyalty and devoted interest were Professor Alphaeus Hyatt, Dr. George L. Goodale, Walter Faxon, and Mr. Alexander Agassiz He frequently visited Dr Goodale and after the latter's death he sent to his widow lilies of the valley every Christmas as long as she lived. His sympathy went out especially to children, whom he dearly loved and he entered into their joys with a spirit of comradeship that won their deep love and admiration. He planned with children trips to the circus, or a sleigh ride, or to the theatre, when he was the life of the party. He was very fond of animals as pets, especially dogs, and anyone who would abuse a dog roused his wrath. Personally very generous, he hated all meanness, sham, or hypocrisy with a violent detestation.

During his later years, when crippled by arthritis and much of a recluse, his close friends, Dr Alfred M Tozzer of the Peabody Museum, and Miss Gertrude A. Thurston, his former secretary at the Museum, gave him most devoted care

Henshaw did not publish extensively and his principal publications were on insects. Dr. P J. Darlington, Jr of the Museum of Comparative Zoology kindly gave me a very complete list of his publications 1885, List of the Coleoptera of America North of Mexico, Am Entomological Soc , 161 pp , of which he published supplements in 1887, 1889 and 1895 He also published, 1889–1896, Bibliography of the more important contributions to American economic entomology in five parts, over 700 pages, Washington, U. S Dept of Agriculture, Division of Entomology, and in 1898, The entomological writings of George Henry Horn, Trans. Am Entomological Soc , vol. 25 pp., XXV–LXXII. Besides these, he published some thirty other papers, mainly on insects, also obituary notices of his close friends, Dr. H A. Hagen, Prof. Alpheus Hyatt, Roland Hayward and Walter Faxon, and as well his annual reports in the Museum of Comparative Zoology.

Besides his natural history work, Henshaw was essentially a bibliophile and did an immense amount in building up to completeness the libraries with which he was connected. In addition, he had been acquiring for long years a very extensive collection of Gilbert White's Natural History of Selborne. Many years ago he told me that he had over 100 editions of that work. Mr. Thomas Franklin Currier of the Widener Library at Harvard writes me: "I feel certain that nowhere else is there gathered together so complete and comprehensive a collection of materials relating to the author of the Natural History of Selborne, embracing not only books and pamphlets, but manuscripts, prints, photographs . . . and Henshaw did not stop with mere collecting; he knew the inside of his books . . . A fairly complete scientific bibliography of White could

probably be made without going out of the Henshaw collection." This great White collection, with his other books and manuscripts, Henshaw in his will left to the Bodleian Library at Oxford, with the feeling that as an English work it most properly belonged there.

ROBERT T JACKSON

FREDERICK LAWTON
(1852–1941)

Fellow in Class III, Section 1, 1921

Frederick Lawton, lawyer and judge, was born at Lowell, May 10, 1852, the son of James and Sarah (Priest) Lawton. He received his early education in the public schools of Lowell and graduated with the degree of A B. from Harvard University in the class of 1874. Then followed a period of teaching, first at Chicopee, Mass. and later for three years as principal of the Brookline High School. He studied law in Lowell in the office of Charles F. Howe, Esq. and was admitted to the bar of Massachusetts in 1880. He then engaged in general practice in Lowell in association with his brother George F Lawton, who was later for many years Judge of Probate for Middlesex County.

In the same year in which he began the practice of his profession Frederick Lawton married Helen Mack of Lowell, the daughter of a well-known business man and former mayor of that city There are two sons of this marriage, Richard M. Lawton and John S. Lawton. The marriage was a preeminently happy one. Mrs Lawton was a woman of high intellectual attainments. The Lawton home, first in Lowell, and later in Boston, to which city the family moved in 1908, became and continued for nearly forty years to be a center of attraction for many persons of culture and learning. Mr. Lawton in close collaboration with his wife developed wide interests in many fields of reading and study far remote from the confines of his profession. These were pursued continuously and systematically and were supplemented by frequent trips to Europe for which careful preparation was made by the study of the history and language of the countries to be visited.

Mr. Lawton's activities included three years in the State Senate as the representative of his Lowell district, beginning in 1893 He was a trustee of the Lowell Textile School and of Rogers Hall School in Lowell. He was interested in the Mechanics Association there He was a member of the Harvard Club, of the Union Club, and of the St. Botolph Club in Boston

In 1900 Governor Crane appointed him an Associate Justice of the Superior Court of Massachusetts. Upon his twenty-six years of service to the State in this high office rests his principal claim to public remembrance and gratitude. To the essential virtues of impartiality and unquestionable integrity Judge Lawton added the equally important virtue of unfailing devotion to duty. He was dignified in manner, rapid in the dispatch of business, quick and decisive in his rulings, and diligent and prompt in disposing of reserved cases His charges to juries were clearly expressed and carefully adapted to the requirements of each case. Although he performed continuously for many years the arduous labor of hearing litigated cases he never fell a victim to the mental weariness and flagging of interest which after a time has lessened the usefulness of many capable judges The strong sense of humor which made him an exquisite raconteur among his guests at home came to his aid on the bench and kept keen and active his interest in the human drama which was constantly unfolded in his court room. The beginning of each new day found him fresh and eager for whatever task it might bring. Another helpful characteristic was his liberal attitude of tolerance of the opinions of others which made him ready to listen to all arguments, even though he might be inclined to disagree with them, and to consider cases from all possible points of view.

It would be impossible to do more than to summarize in general terms Judge Lawton's work upon the great trial court of his native state. That court was one of general jurisdiction of actions at law, suits in equity and criminal prosecutions. Its work was growing rapidly during the period of his service upon it. When he took office there were eighteen justices. When he retired the number had increased to thirty-two. He carried at all times his full share of the burden. He sat as occasion required in all parts of the Commonwealth. He was everywhere a favorite with the clerks and officers who

served under him in his sessions. He was universally respected and trusted by the bar. He tried cases of all kinds from those involving ordinary commercial transactions and money interests to those involving divorce, contested wills, and murder. He tried both jury cases and cases without juries in which he determined both the facts and the law. The number of cases he heard would be counted in the thousands His reputation grew steadily with the advance of years and accumulation of experience.

The death of Mrs Lawton in 1919 was a great blow to Judge Lawton Nevertheless he continued his work with unabated zeal, and his friends continued to find a cordial welcome and good company at his Boston apartment Not only did his children keep in close touch with him at all times, but in addition a peculiarly intimate and comprehending relationship grew up between the judge and his grandchildren and their young friends who frequently visited him

In 1926, at the age of seventy-four, he retired from the court while still in apparent good health. In 1930 he was again called to public service to succeed Judge Fessenden as the representative of the Superior Court on the Judicial Council, a permanent board established by law for the investigation of the judicial system and the recommendation of improvements in the administration of justice For five years he regularly attended the meetings of the Council Although it might, perhaps, have been expected that Judge Lawton would incline somewhat towards the conservative side on questions of change, it is said on good authority that he took a generally progressive position and that he was ready to throw his weight on the side of change whenever it seemed likely that good could be accomplished.

At length advancing years took their inevitable toll in declining strength After a long illness Judge Lawton died at his Boston apartment on March 30, 1941 If he had lived a few weeks longer he would have been eighty-nine years of age He will be remembered and honored chiefly for his long, faithful, and able service as a justice of the Superior Court, but by the survivors of those who were fortunate enough to be admitted to the inner circle of his home he will be remembered more intimately as a gracious host and a charming gentleman.

STANLEY E. QUA

HERBERT VINCENT NEAL
(1869–1940)

Fellow in Class II, Section 3, 1914

Herbert Vincent Neal, biologist and teacher, was born at Lewiston, Maine, on April 3, 1869. On February 21, 1940, he met accidental death on a Texas highway while driving from Mexico City to California He is survived by his wife, Helen Phillips Howell of Southold, New York, to whom he was married on June 8, 1899, and by three children, Margaret and Helen (twins, born February 26, 1901) and John Howell (born July 13, 1906).

He received his bachelor's degree (A B) at Bates College in 1890 and during the next two years served as instructor in history and Latin at St. Paul's School, Garden City, New York. In 1892 he entered Harvard University as a graduate student in biology His chief work was done in association with Professor Edward L. Mark It resulted in a doctorate thesis (1896) entitled "The Segmentation of the Nervous System in Squalus acanthias. a Contribution to the Morphology of the Vertebrate Head," published in the Bulletin of the Museum of Comparative Zoology at Harvard College, volume 31, 1898 From Harvard University he received the following degrees. Bachelor of Arts in 1893, Master of Arts in 1894 and Doctor of Philosophy (in Zoology) in 1896

After his four years at Harvard he spent a year (1896–97) in Europe continuing work on his doctorate problem, mainly at Munich in the laboratory of C von Kupffer, an authority on the development of the head of vertebrates.

At the end of his year abroad, Neal returned to become Professor of Biology at Knox College, Galesburg, Illinois Occupying this position for sixteen years, he became known as an unusually effective teacher and as a competent and constructive biologist. In 1913 he succeeded the late John Sterling Kingsley at Tufts College and served there as Professor of Zoology until his retirement in June, 1939. From 1924 to 1935 he also acted as Dean of the Graduate School.

He was Curator of the Barnum Museum of Tufts College. In 1931 the honorary degree of Doctor of Science was conferred upon him by Bates College

Dr. Neal was actively associated with biological laboratories on the coast of Maine He became assistant Director of the Harpswell Laboratory in 1908 and served as Director from 1913 to 1917. He became a trustee of the Mount Desert Island Biological Laboratory in 1921 and was Director from 1926 to 1932. His enthusiastic interest gained for these institutions much material assistance and helpful support Also he was a member of the Corporation of the Marine Biological Laboratory at Woods Hole and of the Corporation of the Bermuda Biological Station for Research. He was a trustee of Bradford Junior College and of Bates College.

Neal's early scholarship is attested by his membership in Phi Beta Kappa and Sigma Xi Later he acquired membership in the following societies· American Association for the Advancement of Science (Secretary of Section F, 1913–20), American Academy of Arts and Sciences, American Society of Naturalists, American Society of Zoologists (Secretary-Treasurer of Central Branch 1910–11, President of Society, 1930), Association of American Anatomists, Boston Society of Natural History, The Illinois Academy, The Russian National Academy of Science (Corresponding Member). As a Fellow of The American Academy of Arts and Sciences, he rendered important service for four and a half years (1929–34) as Editor and Chairman of the Committee of Publication of the Academy.

Some men are born teachers, others have teaching thrust upon them. It was Neal's genetic good fortune to possess those inherent peculiarities, intellectual and emotional, which enable one human mind to reflect truth into others The brightness and clarity of his mind, its ability to discriminate between the vitally relevant and the unimportant, its keen appreciation of all that is implied by the complexity, inter-relation, continuity and progressive development in the living world made this reflection far more than a literal delineation of tangled reality. His mind focused deeply into that reality and projected a picture of an organic world whose overwhelming diversity and complexity were even exceeded by its evidences of order, harmonious adaptation, integration of smaller into greater living units, and something which has at least the external appearance of a persisting purpose. In all of his teaching the deductions from biology were brought to focus on the problems of the origin, nature and destiny of the human organism. His better students derived from lasting inspiration. Those who were incapable of seeing all that he put before them at least knew that there was something there and they admired and respected him. Although often heavily burdened with teaching responsibilities, he always gave to his students ungrudgingly of his time and energies. He could have done many other things but he always put the teaching first because he loved the doing of it and because he was deeply interested in the human beings who were his students. Many of them are now engaged in medical or other scientific work

Neal's contribution to the science of biology is not to be measured by the number of titles of his published work The list is not long Its titles indicate his persisting interest in the subject which first attracted him—the perplexing problems presented by the segmental structure and arrangement of nervous and other organs in the head of vertebrates His earlier papers constitute a substantial addition to our knowledge of the embryological facts and offer much toward the interpretation of them Later papers deal with the embryonic origin of nervous elements. But it was in the direct impact of his forceful personality and invigorating teaching upon a continuous procession of students over a period of nearly a half century that he did his most important service to science

Much of his time in the last few years of his life was given to the writing of books designed to serve as texts of somewhat advanced nature—a "Comparative Anatomy" (of vertebrates, 1936) and a "Chordate Anatomy" (1939), both with some collaboration from H W. Rand of Harvard University. At the time of his death he had in nearly completely form the manuscript for a book which was intended to express his views concerning the biological origin and nature of man and which, it is to be hoped, will tell us much more than is widely known of the author's fine philoso-

phy of life. It is much to be desired that this manuscript should find early publication.

Neal's dominating concern with problems of human biology made it inevitable that his zoological interest should have centered on the vertebrate animals. It was highly appropriate, therefore, that in his position at Tufts College he should have succeeded John Sterling Kingsley, eminent for his work in the field of vertebrate comparative anatomy. To Kingsley's extensive knowledge and constructive research in anatomy, Neal added interpretation and philosophical insight.

From his student days onward it was evident that the detailed facts of biological structure and function were of interest to Neal chiefly as data which might yield some satisfaction to the common craving for an "explanation" or "interpretation" of "life" or might give us an answer to our query as to the "meaning" of life—if, indeed, it has any meaning In 1934 he published a small book (87 pages) entitled "Vitalism and Mechanism—a Discussion " It consisted merely of letters exchanged, over a period of many years, between him and James F. Porter, a friend from graduate-student days. Porter, a business man of sensitive and artistic temperament and scientific interests, argues for mechanism. Neal's letters express vigorously his dissatisfaction with mechanism and his conviction that "by no hocus-pocus can mind be conjured out of matter."

Neal's philosophy is best judged by a philosopher. Tufts College, on April 21, 1940, held a memorial service for him. At this service his friend, William Ernest Hocking, referred to him as "a colleague in the teaching of philosophy" and spoke at some length concerning Neal's philosophy of biology The following is quoted from Hocking's address. Speaking of the element of wonder as an accompaniment of scientific outlook—". . . Herbert Neal was a man to whom this element of wonder became an imperative. He saw that in the ideal of self-forgetfulness, which is part of the greatness of the scientific spirit, there lurked a danger that the scientist might *forget himself* as a part of that phenomenon which is to be understood. Consciousness, the capacity for pleasure and pain, the power of making judgments of good and evil, of right and wrong,—this extraordinary power of setting up an ideal of truth for truth's sake which is the very heart of the scientific code,—these powers are also products of the living universe. Evolution has produced marvelous organisms; but it has produced also something more marvelous,—organisms which are *aware of* marvelous organisms, and which can consider the whole complex history, debouching in themselves, and speculate about it. That Nature has produced the human body is a marvel; that it has produced the Thinker is more marvelous still."

"It was the peculiar insight of Herbert Neal that he could not forget, nor allow his students to forget, this double nature of the problem of evolution. Could Nature have produced the body without producing the mind? Could Nature have evolved the human body without evolving the human mind?" Never accepting naïve mechanism and finding a vitalism which invokes non-mechanical or "vitalistic" agencies equally inadequate, he believed that " . . the answer had to be sought, not in any detail of the process, as if mind—hitherto absent from the universe—had one day *emerged*, as an incalculable new quality,—but in the character of the universe as a whole, which *never was* devoid of mentality and meaning. It is not for nothing that livingness is felt to be present in the whole." For Neal " the presence of a living character in Nature as a whole was *the reality*, the deepest reality with which we have to do . "

In addition to his philosophy of biology and life, but in every way consistent with it, Neal held a philosophy of human *living* Of the former he was ever ready to talk and did so with characteristic eloquence and earnestness. Of the latter he rarely spoke; yet it was far better known to his associates than was the former because his daily living gave to it more vivid expression than could any words. He lived as one who had been privileged to spend a limited time in some enchanting country. No landscape, no adventure which that land afforded was to be missed. He therefore lived actively, intensely. His nearest approach to idleness was time spent in contemplation of the world's beauty. But it was not a foreign land in which he sojourned He felt himself to be a part of a living universe. He therefore found the world altogether friendly. He saw in it meanness and evil and he hated them, but he

hated no human being. He had only compassion for the man in whom evil resided.

The breadth of his capacity for appreciation was extraordinary. The music of Bach he enjoyed, not as a duty but from the heart and he took pleasure in modern light music—of the better sort. His appreciation of Shakespeare was equalled by his delight in a Charlie Chaplin comedy. But the morbid sordid realism which some recent plays affect aroused his complete disgust. Emerging from a theater late one evening after seeing such a play, he said to the friend with him, "Now let us take a long walk in the cold clean air and under the starlight and get that out of our systems." He was to a surprising degree familiar with music, literature, painters and paintings. He was more than merely passively artistic. His water colors and his playing of the violin revealed capacities which might have been developed far if he had not chosen science He traveled much, always with camera in hand. His collection of lantern slides, colored by himself, was the envy of professional photographers. The wonder is that he was able to do such a diversity of things and to do them all well.

Neal was loyal to his responsibilities as a citizen. He was always actively interested in social, civic and political affairs. He was not so academic that he could not serve a three-year term (1906–09) as alderman from the Sixth Ward of Galesburg, Illinois. In June, 1918, he volunteered for service under the Young Men's Christian Association in its work with the Italian army in the "World War" He was sent to Italy in August, 1918, and served there until August, 1919. From January to July, 1919, he was stationed at Genoa, acting as Regional Director He held the rank of Captain in the Italian army.

Neal's joy in living radiated from him. All who knew him marveled at his spirit of eternal youthfulness. The gracious and generous hospitality of his home will always be remembered by his students and friends. If all men could live by Neal's philosophy, world wars would be replaced by world tolerance and world friendliness. Science and the arts would flourish. And each day of human living would mark some progress in the cooperative striving toward the realization of all that is finest and noblest in the potentialities of the human organism.

HERBERT W. RAND

ALFRED BARTON RENDLE
(1865–1938)

Foreign Honorary Member in Class II, Section 2

Alfred Barton Rendle was born in London, January 19, 1865, the eldest child and only son of John Samuel and Jane Wilson Rendle. He was educated at London schools and at St. John's College, Cambridge. There he came under the stimulating instruction of S. H. Vines Probably he would have liked nothing better than to remain as a member of the school of research which Vines was then endeavoring to build up; but the latter's removal to Oxford put an end to any such hope. Rendle, in need of a position, applied for and got one as Assistant in Botany at the British Museum, left vacant by Ridley's transfer to Singapore.

Although the change from physiological investigation under Vines to the career of a taxonomist and museum official came about fortuitously, it was not made without conviction. Rendle had always been interested in classification and he proved a capable systematist in the British tradition. He steadily advanced in the Museum, becoming Keeper of Botany in 1906 and holding that post until his retirement in 1930

He found time and energy for various activities outside his immediate duties. He served the Linnean Society as member of the Council, Botanical Secretary (1916–23), and President (1923–27) He took an active part in the work of the Royal Horticultural Society and was awarded two of its medals For twelve years he was evening lecturer on botany at the Birkbeck Institute. He did much for the conservation of the native British flora. He took a lively interest in bibliography, no doubt fostered by long association with James Britten I well remember the warmth with which he received a minor discovery of mine in that field —as I remember the almost fatherly hospitality with which he saw to it that I, a first-time visitor to the Museum, should miss nothing to my pleasure or advantage.

No taxonomist of Rendle's time could escape questions and controversies in nomenclature; though said to have had no great liking for the

subject, he was very much concerned with it. He aided in drawing up the original International Rules of 1905, served on the editorial committee of successive congresses and became its head after Briquet's death. Following the Congress of 1905 he prepared, in collaboration with Britten, a list of British seed-plants and ferns in order to test the workings of the then new rules. Britten, a bibliographer rather than a practical taxonomist, inclined to the radical and uncompromising in matters of nomenclature; the list applied certain provisions of the rules not wisely, but too well. However, for that very reason it went far to bring about the formulation and prompt incorporation into the rules of the useful principle of illegitimate names.

An administrative officer of a museum must often sacrifice his own productivity to the duty of keeping its collections in condition for the use of others The bulk of Rendle's published work is not great, and its direction was often determined by the immediate needs of the Museum. One major enterprise, the Flora of Jamaica, begun in 1910 in collaboration with William Fawcett, he initiated and carried well toward completion, five of its seven projected volumes have been published when he died. The work is in the tradition of the great series of British colonial floras; Rendle's future reputation will rest mainly upon it

His one other large work—two volumes on the classification of flowering plants—sprang from his teaching. He believed in the educational usefulness of taxonomic botany—it required, he wrote, a minimum of apparatus and forced the student to systematize observed facts. Also, like many working taxonomists, he distrusted phylogenetic conjecture, none the less when it was his own He maintained that "certainty of identification" was "more important than guesses at affinity, particularly by those with little knowledge of generic and specific differences."* Accordingly, his text-book is deliberately conservative, following the Eichlerian system closely, and makes little attempt at originality. Possibly for that reason, it holds a place among the standard works of its kind

* Ramsbottom in Proc. Linn Soc. London 150: pt 4, p. 329

Rendle was a regular attendant at scientific conventions, often in distant countries. He was taken ill while on his way to one of these, a meeting of the British Association in India late in 1937, and was brought home to die, January 11, 1938

C A. WEATHERBY

CHARLES WARDELL STILES
(1867–1941)

Fellow in Class II, Section 4, 1921

Dr. Charles Wardell Stiles, for many years in the U S. Public Health Service, Washington, D. C., in which he became Medical Director prior to his retirement from active duty on October 1, 1931, died of myocarditis at the U. S. Marine Hospital, Baltimore, on January 24, 1941.

He was born in Spring Valley, N. Y., on May 15, 1867, and received his early education at Wesleyan University, Middletown, Connecticut, later studying at the Collège de France, the University of Berlin, the University of Leipzig, the Pasteur Institute, and the Trieste Zoological Station. He received his Ph.D. degree at the University of Leipzig in 1890, under the famous parasitologist, Leuckart, and was awarded a number of degrees in this country, including an honorary M.D. from the University College of Virginia, in 1913.

Dr. Stiles' professional career began in 1891, when he was placed in charge of the Zoological Laboratory of the Bureau of Animal Industry, U. S. Department of Agriculture In 1902 he joined the U. S Public Health Service, as zoologist, becoming in turn professor of zoology, assistant surgeon, and finally medical director. From 1892 he gave lectures on medical zoology and held teaching positions in Georgetown University, the Army Medical School, Johns Hopkins University, and the Naval Medical School. Since 1931 he had been an associate of the Smithsonian Institution, and professor of zoology at the Rollins College, winter faculty, in Florida. He was a member of numerous American and foreign scientific and medical societies. In 1892 he was elected foreign correspondent, of the Société de Biologie, France; in 1896 foreign correspondent of the Académie de Médicine, France, and in 1899 corresponding member of the Zoölogical Society of London.

In addition Dr. Stiles was active in his fields as scientific secretary of the Rockefeller Commission for the eradication of hookworm, honorary custodian of the helminthological collections in the U. S. National Museum, secretary to the advisory commission of the Smithsonian Table at Naples Zoölogical Station, secretary of the International Commission on Medical Zoölogy, and secretary of the International Commission on Zoological Nomenclature He served also, from 1895–1930, as U. S. delegate to international zoological congresses in Leiden, Cambridge, Berlin, Berne, Boston, Gratz, Monaco, Budapest, and Padua. His mental capacity for weighing the quasi-legal questions involved in taxonomic tangles, and his sound judgment in the formulation of international rules to govern nomenclatorial procedure made him invaluable in this field.

During 1898–1899 he was detailed by the Secretary of Agriculture as agricultural and scientific attaché to the U S. Embassy at Berlin, and his report published in 1901, particularly the part relating to his investigations on trichinosis, furnished convincing and important data

The subjects of his many publications relate chiefly to parasitology and to human and veterinary medicine, and include studies on parasitic protozoa, hookworm and rural sanitation, trematodes, cestodes, anthelmintics, surra, verminous diseases of cattle, classification of ticks, zoological classification, and many others. Perhaps he is best known for his recognition of hookworm disease as an important health problem in certain regions of the Southern States and for the demonstration here of a species distinct from the old-world hookworm. Other outstanding accomplishments of Dr. Stiles are the preparation of the Index-Catalogue of Medical and Veterinary Zoology (in collaboration with Dr. Albert Hassall), his Monographs, Bulletins, and the Key-Catalogue of the Parasites of Man and Animals, indexed in all the more important languages, and utilized the world over by parasitologists.

The thoroughness, accuracy, and high standard of Dr. Stiles' scientific investigations, his ability to analyze and evaluate data, to clearly and impartially present the facts, and his skill in deducing accurate conclusions, serve as an inspiration and guide to other workers in the field of parasitology.

E. E. Tyzzer

HENRY TABER (1860–1936)

Fellow in Class I, Section 1, 1891

Henry Taber was born at Staten Island, N Y. on June 10, 1860 and died at Worcester, Mass. January 6, 1936, he is buried beside his wife in Princeton, Mass, on one of the high plateaus of Mount Wachusett. He was the eldest son of Charles Corey Taber, a cotton dealer and broker of New York city, and his wife Cornelia Frances Martin, of Flushing, L I, and was a descendant of Philip Taber who came from Essex, England to Plymouth, Mass in 1630.

Henry Taber entered Yale with the class of 1881, leaving college for a time on account of illness, however, he became a member of the class of 1882 in the second half of the junior year. He had been pursuing a course in mechanical engineering, but feeling that he was unfitted for this career he was permitted to substitute a special course in mathematics for part of the work. His membership in Berzelius and other Yale clubs was a source of great pleasure to him as he returned to reunions in later years.

The next three years were spent in graduate mathematical study under the great Sylvester, at the Johns Hopkins University where he was awarded the Ph D. degree in 1888 After a year as an assistant he became a docent in mathematics at Clark University, then, as assistant professor (1892–1903) and professor (1903–21) he was an associate of Professor W E Story and very active in mathematical research. He retired as professor of mathematics emeritus in 1921.

Clark University was organized for strictly post-graduate study, and did not aspire to compete with other institutions in the work that is generally recognized as undergraduate. Thus a very distinguished group of scholars was assembled on its Faculty. But with the founding of the University of Chicago and a changed attitude of the founder of Clark, a staggering blow was dealt to the institution when many of its faculty, including the fine mathematician Oskar Bolza, decided to go to Chicago Of the 24 candidates for the Ph.D. in mathematics, presented at Clark

by Professors Story and Taber during 1892–1917, five had worked under the direction of Doctor Taber, namely: E. R. Rettger, S. E. Slocum, R. B. Allen, J. A. Bullard, and S. Zeldin.

His chief mathematical interests were in the fields of matrices and bilinear forms, continuous groups, and hyper-complex numbers. More than thirty of his papers and memoirs were published in *Amer. Jl. Math.* (1890–1916), Amer. Acad. A. Sci., *Proc.* (1891–1913); Amer. Math. So. (a) *Bull.* (1894–97), (b) *Trans.* (1904), Int. Congress Mathems., Chicago, *Mathematical Papers* (1896); *Mathem. Annalen* (1895–1917); *Math. Reviews*, Story (1897); Paris, *Comptes Rendus* (1906).[1] Already in 1893 he was one of only eleven American mathematicians presenting papers at the International Congress of Mathematicians in Chicago. On the invitation of Professor Eduard Study, during sabbatic leave in 1906, he delivered a course of lectures on the theory of groups at the University of Bonn. In 1912 Dr. Taber was elected a vice-president of the American Mathematical Society. He became a fellow of this Academy in 1891

He was married in 1886 to Fanny Lawrence of New York, who died in 1892; they had three daughters who are still living. Of Dr. Taber's brothers, Robert Schell Taber (1865–1904) was a famous actor (Julia Marlowe's first husband), and Edward Martin Taber (1863–1896) an eminent American landscape artist (see R. Cortissoz, *American Artists*, New York, 1923, and S. Isham, *American Painting*, New York, 1927). In appearance Dr. Taber bore such a strong resemblance to the English actor Sir Henry Irving that when he was in London, on being solicited for alms he was addressed as "Sir Henry." He was a member of the Quinsigamond Boat Club, of Worcester, and an excellent tennis player. His religious affiliations were Episcopalian He had a wide range of interests, and a remarkable memory, and he read widely in other branches of science than his specialty, such as chemistry, physics, and medicine. But he was also a great student of history and anthropology, and took delight in literature, art, music, drama, and dancing (especially Pavlova's). He had a highly developed sense of humor, rejoiced in human contacts, and was ever ready to champion the cause of one whom he felt wronged. An old friend has written to me, "His genial, light-hearted, highstrung personality might easily give a stranger little impression of taking himself seriously. Life was to him what Shakespeare said it is, and his care was to act it beautifully."

R. C. ARCHIBALD

FRANK BURSLEY TAYLOR
(1860–1938)

Fellow in Class II, Section I, 1925

Frank Bursley Taylor was son of a leading lawyer of Fort Wayne, Indiana. His father was also a member of the Mississippi River Commission, and his stay at Harvard was co-eval with mine. It is not surprising that his attention was early called to Physiographic problems, so that when his health made indoor work harmful to him he took up with a background of training at Harvard the study of the old shore lines, that surround the Great Lakes and are well marked on Macinac Island, where he had a summer home, and from which he obtained his wife. They traced these shore lines together and in that work I first met him and gave him the first money he ever earned as a professional geologist. With the study of the shore lines it was natural for him to study the ice sheet and its recession upon which they depended for their origin. He became an authority and prepared the Niagara folio of the U. S. Geological Survey tracing the history of Niagara Falls. The origin of glaciation was linked with that of the origin of the earth by T. C. Chamberlin, and Taylor went on to consider the origins of the mountain ranges and this led to the so called Taylor-Wegener hypothesis relative to continental drift. On this he published some ten papers. He also thought a good deal about astronomy and the evolution of the Solar System and published a book. I append

[1] Dr. Taber's complete Bibliography for the years 1890–97, and analyses of many of his papers, may be found in *Clark University 1889–1899. Decennial Celebration* (Worcester, Mass., 1889), p 548–549, 73–83; and *Clark University . . . Report of the Presidents and Departments 1916*, p 12–14. See also Yale University *Obituary Record for the years 1935–1936;* Yale University, *Twenty-fifth Reunion Book of the Class of 1882*, G. L. Randall, *Taber Genealogy Descendants of Thomas son of Philip Taber*, New Bedford, Mass., 1924, p. 244, 882.

letters from him to me of bibliographic interest. He was broad minded enough to change from time to time as he absorbed new facts and was good at drawing maps to illustrate his ideas.

As to his astronomic ideas it is only fair to him to quote from a letter to Leverett as well as to me appended and remark that the publication of the book was forced on him by a well-to-do father who wanted to file a caveat on what he considered his son's great ideas

In the field connecting geology and cosmogony it is not surprising that his speculations like most others have not been accepted.

On April 24, 1899 he was married to Minnetta Amelia Ketchum who helped him in many ways

Beside the American Academy he was a Fellow of the American Association for the Advancement of Science, of various local societies and a member and contributor to the Michigan Academy of Science and others.

His memorial as Fellow of the Geological Society of America which includes genealogical data and bibliography was prepared by Frank Leverett with whom he was intimately associated in his work in the Great Lakes region and its glacial and post-glacial geology, and appears in the Proceedings of the Geological Society of America for 1938, pp 191–200. A shorter abstract appeared in Science, Aug. 5, 1938, p. 121–122, and there were besides the customary newspaper notices a tribute by Agnes Yarnell in the Fort Wayne News Tribune and editorials in the Ft. Wayne Gazette of June 16, and Journal of June 12, and the class memoirs prepared by John C. Merriam, H. U 1886.

To Leverett's bibliography may be added a posthumous paper in the Scientific monthly (July 1939, Vol. xlix, pp. 49–56) "Geological story of the Great Lakes."

As he wrote to Leverett·

"I am quite free to admit that my efforts to point out the cause of continental crustal movements are largely speculative although I claim to have a few very strong evidences in my favor But in gathering together the facts that show the character of the crustal movements, and their direction and amount of movement in the several continents I think I have followed much more sound and careful scientific methods."

A. C. Lane

Letters follow·

420 Downing Ave.
Fort Wayne, Ind.
Feb. 14, 1925.

Prof. Alfred C Lane,
22 Arlington Street,
Cambridge, Mass.
My dear Lane.

Yours of Feb 3 is received. It is rather funny that you should write just at this time and say the things that you do, for the thing you are after is not yet in existence, but you are just in time probably to get what you want Here is a little story. The lines you read in the last Who's Who told a lie, thanks to the stubborn meanness of an editor and his advisors, and partly also to my own oversanguine expectations. More than three years ago I prepared two short papers, eleven typewritten pages each under the titles "The Great Satellites of the Giant Planets," and "The Growth of the Planetary System as Revealed in Its Vestiges " I did this in one more desperate effort to get my ideas into a form in which they would be received and published by some scientific journal. I was determined to do no more private printing, except as a last resort These papers were still in the editor's hands when the last day of grace for Who's Who came. I felt sure the papers would be accepted, but—it simply was a case of counting the eggs before they were hatched I was disgusted. In my sanguine expectations, I had sent the title in to Who's Who, and then the confounded egg didn't hatch.

Since then I have been working at other things, until a few months ago, when I took up these subjects once more. I think you know the awful struggle I have been thru in endeavoring to formulate my ideas and then to get some one to look at them earnestly and open mindedly It is more than 40 years (Dec 13, 1884) since I hit upon the idea of direct capture as the origin of satellites, and I soon extended it to planets. In July 1891, I started to print my ideas privately, but my plan was altogether too elaborate, and I went broke before I got to the real meat of the subject. It was miserable stuff, worse than nothing, and I have always been glad that the attempt failed.

In June, 1898, when my health seemed unusually threatening, I printed privately a little pam-

phlet of forty pages, a sort of caveat on my ideas, it is no account, excepting as a caveat The astronomical part is as bad as my earlier attempt, but there are four pages in which I state for the first time my idea of the function of tidal and rotational forces in world-geology, in the making of continents, mountain ranges, etc. This little pamphlet is entitled "An Endogeneous Planetary System" I am sending you a copy herewith, with the geological passage marked I sent out only three copies of this pamphlet to geologists, one each to Gilbert, McGee and Chamberlin at the time it was printed About four years ago two copies were sent to non-professional friends, no others were ever sent out It is a sort of precursor of my later papers on continents, mountain ranges etc. I think I sent you a copy of "Bearing of Tertiary Mountain Belt on the Origin of the Earth's Plan" 1910 long ago I enclose also a copy of the abstract of my paper at Washington, April 18, 1923 entitled "The Lateral Migration of Land Masses." But if you wish my latest on this theme, see *Pan-American Geologist* for Feb 1925 In the spring and summer following my father's terrible illness in Boston in Jan. and Feb. 1903, I wrote and printed privately, a book entitled "The Planetary System." This is a fugitive volume if ever there was one, but whether it is a fugitive from justice or from injustice, I have never been able to find out It has pretty nearly everything it it, but is an awful mess.

About 1908, I began to try to find a way to discuss the growth of the Planetary system by inductive methods (in the Planetary System it was mainly deductive). After more than ten years of study and work, off and on, I produced a paper entitled "The Growth of the Planetary System as revealed in Its Vestiges" and in the Fall of 1920 I sent it to Prof. T. C Chamberlin for the Journal of Geology. He had published many papers of his own on the same general theme, but he refused mine Mine, he said, was too astronomical, he advised me to send it to the Astro-physical Journ. (Prof E B. Frost, Editor) I knew there was no use to do that, but I did as Chamberlin suggested, just to see what would happen. Frost sent it back and advised me to send it to Chamberlin; so there I was. I recognized that that paper was objectionable because it was too long. But the theme is so big it is next to impossible to present it adequately in short papers. Nevertheless, I tried once more in the two little papers (11 pages each, typewritten) mentioned at the beginning of this letter They were nicely illustrated. I sent them to the American Journal of Science, but the trip proved to be only an excursion. *Now*, I am in the midst of one more effort to get somewhere with these ideas

This time I hope to realize it in book form, have a publisher in N. Y. in sight. I have it about half written. I can loan you about half the manuscript for a few days. You may read it and return it as promptly as you can. I may include one of the earlier short papers which I intend to work into the latter part of the present paper What I send you will cover my main theme fairly well I enclose pamphlets now; will send you manuscript about Feb. 20

Very truly yours,
(signed) Frank B Taylor

December 13th, 1933.

Dear Lane

Just to remind you that this is the birthday of an idea. On December 13th, 1884, forty-nine years ago today, I first conceived of the idea that the moon became the satellite of the earth by capture directly out of space I doubt if you have ever been much attracted by my "speculations," but I think I may safely call your attention now to the fact that the world is beginning to come my way, very slowly and only a little, it is true, but while I may not live to see the finish, I think that you with your greater vitality may do so.

You are having your own A. A. A. S. party in Cambridge and I suppose you will stay there and not come to Chicago. I hope to go to the Chicago meeting but am not sure. Good health and a Merry Christmas to all of you

Yours
(signed) Frank B. Taylor

HARRY WALTER TYLER (1863–1938)

Fellow in Class I, Section 1, 1902

Harry W. Tyler was born in Ipswich, Mass., April 16, 1863, and died in Washington, D. C., Feb. 3, 1938. He was a son of David M. and

Harriet (Wilcomb) Tyler. After graduating in 1884 with the degree of Bachelor of Science, from the Massachusetts Institute of Technology, he was an assistant and instructor in the mathematics department of the Institute for three years. From this period dates a little booklet *Entertainments in Chemistry; Easy Lessons and Directions for Safe Experiments* In 1887 he was married to Alice Irving Brown of Roxbury, Mass He spent 1887–88 in study at the University of Göttingen, and 1888–89 at the University of Erlangen, where he obtained the Doctor of Philosophy degree under Gordan, his dissertation being entitled *Beziehungen zwischen der Sylvester'-schen und der Bézout'schen Determinante*

In 1890 he returned to the Institute as an assistant professor of mathematics, became an associate professor in 1892, and was a professor from 1893 till he became professor emeritus in 1930; he was head of the department from 1901, and its high distinction to-day is due in no small degree to the wisdom of appointments which he arranged. Furthermore, it was during the last decade of his regime that 190 numbers of *Contributions* of his department, and ten volumes of the Institute's important quarterly *Journal of Mathematics and Physics*, were published. He served also as registrar, as secretary of the faculty, and for many years as president of the Faculty Club at M I T

Professor Tyler was a constant attendant at meetings of societies and congresses in this country and in Europe and his services as secretary and committee chairman were ever in great demand In 1893 he was secretary of the first international congress of mathematicians which was held in Chicago He was chairman of the committee on incorporation of the American Mathematical Society For many years he was prominent in the Association of University Professors and served as its remarkable general secretary from 1916 to 1934. He was vice-president of the Association for 1934 and 1935 and editor of its *Bulletin* until July 1937. He moved to Washington in 1930, and from that time until his death he was a consultant in science at the Library of Congress His winning personality won him many friends and he was especially popular with the local alumni group of the Institute which repeatedly elected him as their president

At congresses he was always an attendant at the sections dealing with pedagogical and historical questions. His *Short History of Science* (New York, 1917) prepared in collaboration with Professor W T Sedgwick was the outgrowth of a lecture course given by the authors for several years to undergraduate classes of the Institute The new edition of 1939, in part a revision but to a great extent a new work, was prepared by Tyler and R. P Bigelow.

Dr Tyler had remarkable executive ability, "energy, patience, initiative and caution, firmness and tact, dignity and (not least valuable) a dry and penetrating sense of humor—the expression of which, when such expression would have been inopportune, he was almost always (with some difficulty one suspects) able to restrain "[1] He became a fellow of the Academy in 1902, the year when his fellow mathematicians rated him as 77th among the leading 80 mathematicians of the United States and Canada.

Of his four daughters the eldest, Margaret Tyler, is a physician, and associate clinical professor in obstetrics and gynecology at the Yale University School of Medicine.

R C ARCHIBALD

[1] A O Lovejoy, "Harry Walter Tyler 1863–1938," Amer Assoc Univ Prof, *Bulletin*, v 24, 1938, p. 219–221 See also *Science*, n s, v 87, 1938, p 181

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99 Henry Lefavour Boston
31 Robert Bruce Lindsay Providence, R I
01 Theodore Lyman Brookline
34 Louis Williams McKeehan Washington, D C
14 Ernest George Merritt Ithaca, N Y
14 Robert Andrews Millikan Pasadena, Cal
34 Harry Rowe Mimno Lexington
34 Philip McCord Morse Belmont
31 Otto Oldenberg Cambridge
40 J Robert Oppenheimer Berkeley, Cal
34 Leigh Page New Haven, Conn
07 George Washington Pierce Cambridge
41 Isidor Isaac Rabi Cambridge
27 John Clarke Slater Cambridge
37 George Walter Stewart Iowa City, Ia
43 Donald Charles Stockbarger Belmont
37 Jabez Curry Street Belmont
12 Maurice deKay Thompson Brookline
28 Manuel Sandoval Vallarta Mexico, D F
35 Robert Jemison Van de Graaff Belmont
34 John Hasbrouck Van Vleck Cambridge
35 Bertram Eugene Warren Arlington
18 David Locke Webster Palo Alto, Cal
11 Edwin Bidwell Wilson Brookline
13 Robert Williams Wood Baltimore, Md
17 John Zeleny New Haven, Conn

Class I, Section III—*Chemistry*—57

26 Roger Adams Urbana, Ill.
44 Isadore Amdur Cambridge
13 Wilder Dwight Bancroft Ithaca, N Y
07 Gregory Paul Baxter Cambridge
29 James Alexander Beattie Belmont
19 Arthur Alphonzo Blanchard Brookline
14 Marston Taylor Bogert New York, N. Y.
36 Harold Simmons Booth Cleveland, O
11 William Crowell Bray Berkeley, Cal
38 Emile Monnin Chamot Ithaca, N Y
41 George Whiteley Coggeshall Cambridge
42 Samuel Cornette Collins Belmont
24 James Bryant Conant Cambridge
23 Tenney Lombard Davis Norwell
37 John Tileston Edsall Dedham
37 Gustavus John Esselen Swampscott
40 William Lloyd Evans Columbus, O
33 Louis Frederick Fieser Belmont
15 George Shannon Forbes Cambridge
35 Louis Harris Belmont
36 Albert Baird Hastings Brookline
38 Robert Casad Hockett Concord
36 Ernest Hamlin Huntress Melrose Highlands
18 Grinnell Jones Cambridge
19 Frederick George Keyes Cambridge
33 George Bogdan Kistiakowsky Cambridge
15 Charles August Kraus Providence, R. I.
14 Arthur Becket Lamb Brookline
18 Irving Langmuir Schenectady, N. Y.
09 Gilbert Newton Lewis Berkeley, Cal.
15 Warren Kendall Lewis Newton
23 Duncan Arthur MacInnes New York, N. Y
32 Kenneth Lamartine Mark Boston
41 Charles Edward Kenneth Mees Rochester, N Y.
35 Nicholas Athanasius Milas Belmont
36 Avery Adrian Morton Watertown
19 Edward Mueller Cambridge
31 William Albert Noyes, Jr Rochester, N Y.
44 Linus Carl Pauling Pasadena, Cal
14 Samuel Cate Prescott Brookline
39 Clifford Burrough Purves Montreal, Can
79 Robert Hallowell Richards Jamaica Plain
14 Martin André Rosanoff Mt Lebanon, Pa.
28 George Scatchard Cambridge
32 Walter Cecil Schumb East Milton
15 Miles Standish Sherrill Cambridge
20 Harry Monmouth Smith Brookline
34 Leighton Bruerton Smith Beverly
43 Hugh Stott Taylor Princeton, N J
22 Richard Chace Tolman Pasadena, Cal
38 Harold Clayton Urey Leonia, N. J.
41 Harry Boyer Weiser Houston, Tex
39 Frank Clifford Whitmore State College, Pa.
11 Willis Rodney Whitney Schnectady, N. Y.
19 Robert Seaton Williams Belmont
44 Edgar Bright Wilson, Jr Cambridge
41 Ralph Chillingworth Young Arlington

Class I, Section IV—*Technology and Engineering*—47

06 Comfort Avery Adams Philadelphia, Pa.
42 Wilmer Lanier Barrow Concord
33 Harold Kilbrith Barrows Winchester
31 Charles Harold Berry Belmont
41 Edward Lindley Bowles Wellesley
25 Vannevar Bush Washington, D C.
34 Otto Gustav Colbiornsen Dahl New York, N Y
34 Chester Laurens Dawes Cambridge
38 Alfred Victor de Forest Cambridge
34 Jacob Pieter Den Hartog Wellesley Hills
43 Bradley Dewey Cambridge
20 Theodore Harwood Dillon Washington, D. C.
41 Charles Stark Draper Newton
22 Gano Dunn New York, N. Y.
21 William Frederick Durand. Palo Alto, Cal.
27 Gordon Maskew Fair Cambridge
32 Glennon Gilboy Lincoln
32 Albert Haertlein Watertown
40 Harold Locke Hazen Belmont
44 Arthur Robert von Hippel Weston
36 Murray Philip Horwood Newton Center

23 William Hovgaard . Brooklyn, N. Y.
34 Jerome Clarke Hunsaker Boston
23 James Robertson Jack Watertown
11 Dugald Caleb Jackson. Cambridge
30 Frank Baldwin Jewett New York, N Y.
01 Lewis Jerome Johnson Cambridge
37 Joseph Henry Keenan Belmont
32 Ralph Restieaux Lawrence Belmont
23 William Henry Lawrence Jamaica Plain
38 John Moyes Lessells Brookline
12 Lionel Simeon Marks Cambridge
44 Richard von Mises Cambridge
34 Edward Leyburn Moreland Wellesley
20 Frederick Law Olmsted Elkton, Md
28 Langdon Pearse Chicago, Ill
13 Harold Pender Philadelphia, Pa
30 Greenleaf Whittier Pickard Newton Center
41 Reinhold Rüdenberg Belmont
30 George Edmond Russell Lexington
39 C Richard Soderberg Weston
14 Charles Milton Spofford Boston
[28] 44 Karl Terzaghi Winchester
23 Edward Pearson Warner Washington, D C
37 Harald Malcolm Westergaard Belmont
40 John Wulff . Cambridge
41 Vladimir Kosma Zworykin. Princeton, N. J

CLASS II—NATURAL AND PHYSIOLOGICAL SCIENCES—212

SECTION I—*Geology, Mineralogy, and Physics of the Globe*—47

15 Wallace Walter Atwood Worcester
41 Alan Mara Bateman New Haven, Conn
38 Marland Pratt Billings Wellesley
21 Norman Levi Bowen Chicago, Ill
16 Isaiah Bowman Baltimore, Md
33 Charles Franklin Brooks Milton
29 Kirk Bryan Cambridge
33 Frank Morton Carpenter Lexington
93 Henry Helm Clayton Canton
09 Reginald Aldworth Daly Cambridge
34 Sterling Price Fergusson Milton
42 Russell Gibson Belmont
17 James Walter Goldthwait Hanover, N H
14 Louis Caryl Graton Cambridge
17 Herbert Ernest Gregory Honolulu, T. H.
21 William Jackson Humphreys Washington, D. C
16 Ellsworth Huntington New Haven, Conn
44 Columbus O'Donnell Iselin ..Woods Hole
95 Robert Tracy Jackson Peterborough, N. H
02 Thomas Augustus Jaggar Honolulu, T. H
10 Alfred Church Lane . Cambridge
25 Esper Signius Larsen, Jr. Belmont
15 Andrew Cowper Lawson Berkeley, Cal.
43 Lewis Don Leet Harvard
16 Charles Kenneth Leith Madison, Wis.
31 George Francis McEwen. . .. La Jolla, Cal.
27 Donald Hamilton McLaughlin . New York, N. Y.
25 Kirtley Fletcher Mather. . ..Newton Center
35 Warren Judson Mead Belmont
21 John Campbell Merriam Washington, D. C.
17 William John Miller Los Angeles, Cal.
32 Frederick Kuhne Morris Cambridge
34 Walter Harry Newhouse Melrose
17 Percy Edward Raymond Lexington
22 Austin Flint Rogers Palo Alto, Cal.
34 Carl-Gustaf Arvid Rossby Chicago, Ill
19 Waldemar Theodore Schaller Washington, D C
12 William Berryman Scott Princeton, N J.
11 Hervey Woodburn Shimer .. Hingham
41 Chester Stock .Pasadena, Cal.
44 Harald Ulrik Sverdrup La Jolla, Cal
17 Thomas Wayland Vaughan Washington, D C.
08 Charles Hyde Warren New Haven, Conn.
14 Herbert Percy Whitlock New York, N. Y.
35 Derwent Stainthorpe Whittlesey Cambridge
15 Bailey Willis Palo Alto, Cal.
15 Frederick Eugene Wright Washington, D C

CLASS II, SECTION II—*Botany*—39

30 LeRoy Abrams Palo Alto, Cal
11 Oakes Ames North Easton
34 Edgar Anderson St Louis, Mo.
15 Irving Widmer Bailey Cambridge
00 Liberty Hyde Bailey Ithaca, N Y
21 Edward Wilber Berry Baltimore, Md.
40 Albert Francis Blakeslee . Northampton
98 Douglas Houghton Campbell Palo Alto, Cal
16 Bradley Moore Davis Ann Arbor, Mich
35 Bernard Ogilvie Dodge New York, N Y
41 Arthur Johnson Eames Ithaca, N Y
21 Rollins Adams Emerson Ithaca, N. Y.
12 Alexander William Evans New Haven, Conn.
29 Joseph Horace Faull Cambridge
00 Merritt Lyndon Fernald Cambridge
44 Paul Rupert Gast Petersham
11 Robert Almer Harper Bedford, Va.
98 John George Jack East Walpole
28 Willis Linn Jepson Berkeley, Cal
27 Ivan Murray Johnston Brookline
34 Donald Forsha Jones New Haven, Conn.
14 Burton Edward Livingston Riderwood, Md
40 Paul Christoph Mangelsdorf Newtonville
42 William Ralph Maxon Washington, D. C.
21 Elmer Drew Merrill Jamaica Plain
10 Winthrop John Vanleuven Osterhout New York, N Y.
27 George James Peirce Palo Alto, Cal.
44 Hugh Miller Raup Jamaica Plain
14 Alfred Rehder Jamaica Plain
30 Karl Sax Forest Hills
34 Edmund Ware Sinnott New Haven, Conn
44 Albert Charles Smith Jamaica Plain
34 Gilbert Morgan Smith Palo Alto, Cal
23 Elvin Charles Stakman St. Paul, Minn.
38 Kenneth Vivian Thimann Cambridge
92 William Trelease. Urbana, Ill.
31 Charles Alfred Weatherby Cambridge

22 William Henry Weston, Jr — Winchester
32 Ralph Hartley Wetmore — Cambridge

CLASS II, SECTION III—*Zoology and Physiology*—66

22 Nathan Banks — Holliston
16 Thomas Barbour — Boston
33 Philip Bard — Baltimore, Md.
09 Francis Gano Benedict — Machiasport, Me
11 Henry Bryant Bigelow — Concord
14 Robert Payne Bigelow — Brookline
35 Charles Henry Blake — Lincoln
20 William T Bovie — Fairfield, Me.
24 Edward Allen Boyden — Minneapolis, Minn
16 John Lewis Bremer — Boston
15 Charles Thomas Brues — Newtonville
28 John Wymond Miller Bunker — Belmont
06 Walter Bradford Cannon — Cambridge
22 Thorne Martin Carpenter — West Roxbury
00 William Ernest Castle — Berkeley, Cal
29 Lemuel Roscoe Cleveland — Jamaica Plain
26 Edwin Joseph Cohn — Cambridge
14 Edwin Grant Conklin — Princeton, N J
23 Manton Copeland — Brunswick, Me
27 William John Crozier — Belmont
17 Joseph Augustine Cushman — Sharon
29 Hallowell Davis — Cambridge
33 Alden Benjamin Dawson — Belmont
25 Samuel Randall Detwiler — New York, N Y
43 David Bruce Dill — Washington, D C
25 Herbert McLean Evans — Berkeley, Cal
34 Cyrus Hartwell Fiske — Lexington
15 Alexander Forbes — Milton
34 John Farquhar Fulton — New Haven, Conn
31 William King Gregory — New York, N Y
36 Frederick Lee Hisaw — Belmont
29 Leigh Hoadley — Cambridge
34 Hudson Hoagland — Worcester
24 Samuel Jackson Holmes — Berkeley, Cal
28 Roy Graham Hoskins — Waban
13 Leland Ossian Howard — Washington, D C
14 Herbert Spencer Jennings — Los Angeles, Cal
13 Charles Atwood Kofoid — Berkeley, Cal.
44 Eugene Markley Landis — Brookline
16 Frederic Thomas Lewis — Waban
33 Frank Rattray Lillie — Chicago, Ill
14 Ralph Stayner Lillie — Chicago, Ill.
17 Richard Swann Lull — New Haven, Conn
43 Brenton Reid Lutz — Melrose
84 Edward Laurens Mark — Cambridge
15 Albert Davis Mead — Providence, R I
27 Axel Leonard Melander — Riverside, Cal
35 Karl Friedrich Meyer — San Francisco, Cal
21 Gerrit Smith Miller — Washington, D. C
28 Thomas Hunt Morgan — Pasadena, Cal.
42 Hermann Joseph Muller — Amherst
95 George Howard Parker — Cambridge
21 Henry Augustus Pilsbry — Philadelphia, Pa
39 Gregory Pincus — Worcester
27 Frederick Haven Pratt — Wellesley Hills
09 Herbert Wilbur Rand — Cambridge
32 David Rapport — Cambridge
23 Alfred Clarence Redfield — Cambridge
34 Alfred Newton Richards — Bryn Mawr, Pa
34 Oscar Riddle — Cold Spring Harbor, N. Y.
37 Alfred Sherwood Romer — Cambridge
25 Alexander Grant Ruthven — Ann Arbor, Mich.
41 Francis Otto Schmitt — Belmont
15 Arthur Wisswald Weysse — Woburn
38 George Bernays Wislocki — Milton
33 Jeffries Wyman, Jr — Chestnut Hill

CLASS II, SECTION IV—*Medicine and Surgery*—60

41 Fuller Albright — Brookline
32 Joseph Charles Aub — Belmont
36 Oswald Theodore Avery — New York, N. Y.
29 James Bourne Ayer — Milton
(28) 32 Franklin Greene Balch — Boston
41 Walter Bauer — Waban
31 George Blumer — San Marino, Cal.
43 Arlie Vernon Bock — Cambridge
36 Charles Sidney Burwell — Brookline
19 Alexis Carrel — New York, N. Y.
31 William Bosworth Castle — Brookline
30 David Cheever — Boston
13 Henry Asbury Christian — Brookline
42 William Irving Clark — Worcester
21 Rufus Cole — Mount Kisco, N. Y
32 Elliott Carr Cutler — Brookline
31 Eugene Floyd DuBois — New York, N Y
44 Maxwell Finland — Squantum
33 Reginald Fitz — Brookline
11 Simon Flexner — New York, N. Y
27 James Lawder Gamble — Brookline
22 Joseph Lincoln Goodale — Ipswich
21 Ross Granville Harrison — New Haven, Conn
27 Percy Rogers Howe — Belmont
21 William Henry Howell — Baltimore, Md
33 Edgar Erskine Hume — Frankfort, Ky
15 Reid Hunt — Boston
34 Henry Jackson, Jr — Chestnut Hill
12 Elliott Proctor Joslin — Boston
43 Chester Scott Keefer — Brookline
23 Roger Irving Lee — Brookline
42 Samuel Albert Levine — Newton Center
29 Edwin Allen Locke — Williamstown
28 Warfield Theobald Longcope — Baltimore, Md
32 Fred Bates Lund — Newton Center
40 William de Berniere MacNider — Chapel Hill, N. C
44 William Malamud — Worcester
34 Leroy Matthew Simpson Miner — Newtonville
26 George Richards Minot — Brookline
41 Alan Richards Moritz — Jamaica Plain
28 William Lorenzo Moss — Athens, Ga.
28 John Howard Mueller — West Roxbury
25 Robert Bayley Osgood — Boston
37 Walter Walker Palmer — New York, N. Y
27 Joseph Hershey Pratt — Brookline
35 Tracy Jackson Putnam — New York, N. Y
34 William Carter Quinby — Brookline
34 Arthur Hiler Ruggles — Providence, R. I.

39	Frederick Fuller Russell	Brookline
39	William Thomas Salter	New Haven, Conn
33	George Cheever Shattuck	Brookline
30	Torald Hermann Sollmann	Cleveland, O.
14	Richard Pearson Strong	Boston
30	Fritz Bradley Talbot	Brookline
44	George Widmer Thorn	Cambridge
14	Ernest Edward Tyzzer	Wakefield
14	Frederick Herman Verhoeff	Brookline
27	Joseph Treloar Wearn	Cleveland, Ohio
40	Paul Dudley White	Brookline
12	Simeon Burt Wolbach	South Sudbury

CLASS III—THE SOCIAL ARTS—174

SECTION I—*Jurisprudence*—39

(24) 32	Francis Noyes Balch	Jamaica Plain
38	Henry Moore Bates	Ann Arbor, Mich
36	Stoughton Bell	Cambridge
33	Harry Augustus Bigelow	Chicago, Ill
36	Wilfred Bolster	Wellesley
36	Claude Raymond Branch	Providence, R I
33	John Dickinson	Philadelphia, Pa
38	Robert Gray Dodge	Boston
31	Fred Tarbell Field	Newton
39	Herbert Funk Goodrich	Philadelphia, Pa.
33	Theodore Francis Green	Providence, R I
38	Frank Washburn Grinnell	Boston
41	Erwin Nathaniel Griswold	Belmont
39	John Loomer Hall	Boston
39	Augustus Noble Hand	New York, N Y.
33	Learned Hand	New York, N Y
39	Albert James Harno	Urbana, Ill
18	Charles Evans Hughes	Washington, D C
38	Melvin Maynard Johnson	Brookline
38	James McCauley Landis	Cambridge
32	Sayre Macneil	Pasadena, Cal
32	Calvert Magruder	Cambridge
31	William DeWitt Mitchell	New York, N Y
31	Edmund Morris Morgan	Arlington
36	Henry Parkman, Jr	Boston
39	Robert Porter Patterson	Washington, D C
01	George Wharton Pepper	Philadelphia, Pa.
11	Roscoe Pound	Watertown
38	William Morton Prest	Boston
36	Stanley Elroy Qua	Lowell
32	Francis Bowes Sayre	Washington, D C
21	Austin Wakeman Scott	Cambridge
36	Sidney Post Simpson	Cambridge
33	Harlan Fiske Stone	Washington, D C
39	Thomas Walter Swan	New York, N Y
32	Edward Sampson Thurston	Berkeley, Cal
38	Bentley Wirt Warren	Boston
(28) 32	Edmund Allen Whitman	Cambridge
43	Charles Edward Wyzanski, Jr	Cambridge

CLASS III, SECTION II—*Government, International Law, and Diplomacy*—28

36	Howard Landis Bevis	Columbus, O.
33	Edwin Montefiore Borchard	New Haven, Conn.
40	Robert Granville Caldwell	Belmont
32	William Richards Castle, Jr	Washington, D C
32	Joseph Perkins Chamberlain	New York, N Y.
33	Robert Treat Crane	New York, N. Y.
35	Tyler Dennett	Hague, N Y
31	Sidney Bradshaw Fay	Cambridge
27	William Cameron Forbes	Norwood
34	Edgar Stephenson Furniss	New Haven, Conn
32	Joseph Clark Grew	Washington, D C
35	Charles Grove Haines	Los Angeles, Cal
41	Hajo Holborn	Hamden, Conn
27	Arthur Norman Holcombe	Cambridge
31	Manley Ottmer Hudson	Cambridge
32	Philip Carryl Jessup	New York, N Y
32	Charles Edward Merriam	Chicago, Ill
19	John Bassett Moore	New York, N Y
13	William Bennett Munro	Pasadena, Cal
41	Gaetano Salvemini	Cambridge
40	Thomas Head Thomas	Cambridge
44	Sarah Wambaugh	Cambridge
43	Payson Sibley Wild, Jr	Cambridge
27	Westel Woodbury Willoughby	Washington, D C
32	William Franklin Willoughby	Washington, D C
14	George Grafton Wilson	Grafton, Vt
27	Quincy Wright	Chicago, Ill
33	Henry Aaron Yeomans	Harvard

CLASS III, SECTION III—*Economics and Sociology*—67

36	James Waterhouse Angell	New York, N Y
36	James Cummings Bonbright	New York, N Y
43	Augusta Fox Bronner (Mrs William Healy)	Boston
44	Douglass Vincent Brown	Brookline
33	Harold Hitchings Burbank	Cambridge
34	John Maurice Clark	Westport, Conn
28	Arthur Harrison Cole	Cambridge
31	Melvin Thomas Copeland	Cambridge
31	William Leonard Crum	Cambridge
32	William James Cunningham	Cambridge
21	Clive Day	New Haven, Conn
32	Arthur Stone Dewing	Newton
41	Carl Rupp Doering	Cambridge
32	Wallace Brett Donham	Cambridge
34	John Franklin Ebersole	Belmont
42	Howard Sylvester Ellis	Berkeley, Cal
36	Fred Rogers Fairchild	Hamden, Conn
36	Frank Albert Fetter	Princeton, N J
12	Irving Fisher	New Haven, Conn
34	Ralph Evans Freeman	Cambridge
13	Edwin Francis Gay	San Marino, Cal
33	Sheldon Glueck	Cambridge
39	Gottfried Haberler	Cambridge
34	Robert Murray Haig	New York, N. Y
41	Earl Jefferson Hamilton	Evanston, Ill
32	Henry Wyman Holmes	Cambridge
34	Edwin Walter Kemmerer	Princeton, N J
34	Frank Hyneman Knight	Chicago, Ill
42	Wassily W. Leontief	Cambridge
36	Roswell Cheney McCrea	Augusta, Ga
34	Robert Morison MacIver	New York, N. Y.

32 Walter Wallace McLaren Williamstown
36 Malcolm Perrine McNair . . .Cambridge
32 Leon Carroll Marshall Chevy Chase, Md.
33 Edward Sagendorph Mason Cambridge
36 Elton Mayo Cambridge
34 Richard Stockton Meriam South Lincoln
34 Harry Alvin Millis Washington, D C.
32 Frederick Cecil Mills New York, N. Y.
31 Wesley Clair Mitchell New York, N. Y.
34 Arthur Eli Monroe Cambridge
32 Harolk Glenn Moulton Washington, D. C
34 Edwin Griswold Nourse Washington, D C.
32 William Fielding Ogburn Chicago, Ill.
42 William Andrew Paton Ann Arbor, Mich
32 Leo S Rowe Washington, D. C.
37 Clyde Orval Ruggles Cambridge
42 Paul Anthony Samuelson Cambridge
36 Thomas Henry Sanders Cambridge
33 Josef Alois Schumpeter Cambridge
43 Benjamin Morris Selekman Cambridge
32 Carl Snyder New York, N. Y.
31 Pitirim Alexandrovich Sorokin Winchester
41 Francis Trow Spaulding Cambridge
31 Oliver Mitchell Wentworth Sprague Cambridge
34 Frederick John Teggart Berkeley, Cal
33 William Isaac Thomas Berkeley, Cal
37 Harry Rudolph Tosdal Belmont
31 Donald Skeele Tucker Belmont
41 Robert Ulich Cambridge
33 Abbott Payson Usher Salem
34 Jacob Viner Chicago, Ill
38 T[homas] North Whitehead Cambridge
32 John Henry Williams Cambridge
36 Joseph Henry Willits New York, N Y.
34 Leo Wolman New York, N. Y
34 Carle Clark Zimmerman Winchester

CLASS III, SECTION IV—*Administration and Affairs*—40

(25) 32 Charles Francis Adams Concord
39 Chester Irving Barnard Newark, N. J
(25) 32 Charles Foster Batchelder Peterborough, N H.
44 Adolf Augustus Berle, Jr Washington, D C
44 Raymond Blaine Fosdick New York, N Y
41 Godfrey Lowell Cabot Boston
43 Ada Louise Comstock (Mrs Wallace Notestein) New Haven, Conn.
42 Donald Kirk David Boston
38 Edmund Ezra Day Ithaca, N Y
41 Frederic Adrian Delano Washington, D. C.
32 Henry Sturgis Dennison Framingham
(28) 32 William Lusk Webster Field Milton
39 Ralph Edward Flanders Springfield, Vt
38 Horace Sayford Ford Belmont
35 Jerome Davis Greene. Cambridge
42 Roger Sherman Greene . .Worcester
44 Ernest Martin Hopkins Hanover, N. H.
(28) 32 Edward Jackson Holmes Topsfield
41 Edward Godfrey Huber . Waban
34 Henry Plimpton Kendall Sharon
44 James Rhyne Killian, Jr . . Wellesley Hills
32 Thomas William Lamont New York, N. Y.
39 Morris Evans Leeds Philadelphia, Pa.
34 Clarence Cook Little Bar Harbor, Me.
36 Dumas Malone Charlottesville, Va.
42 Daniel L. Marsh Boston
33 James Vance May Watertown
02 Herbert Putnam Washington, D. C.
34 Erwin Haskell Schell Cambridge
38 Charles Seymour New Haven, Conn.
35 Henry Lee Shattuck Boston
37 Henry Southworth Shaw Melrose
(28) 32 Payson Smith Orono, Me.
33 Albert Warren Stearns Billerica
36 Clair Elsmere Turner Arlington
(24) 32 Edwin Sibley Webster Brookline
44 Charles Edward Wilson New York
41 Laurence Leathe Winship South Sudbury
(25) 32 Benjamin Loring Young Weston
39 Owen D. Young New York, N Y.

CLASS IV—THE HUMANITIES—187

SECTION I—*Theology, Philosophy, and Psychology*—40

32 Michael Joseph Ahern Weston
32 James Rowland Angell Hamden, Conn
33 John Gilbert Beebe-Center Swampscott
38 Julius Seelye Bixler Waterville, Me
24 Edwin Garrigues Boring Cambridge
28 Edgar Sheffield Brightman Newton
31 Henry Addington Bruce Cambridge
32 Leonard Carmichael Tufts College
36 Robert Pierce Casey Providence, R. I.
28 Walter Fenno Dearborn Cambridge
18 Edmund Burke Delabarre Providence, R I.
33 Curt John Ducasse Providence, R I.
43 Angus Dun Washington, D C.
38 James Everett Frame Princeton, N J
37 Clarence Henry Graham Providence, R. I.
30 William Henry Paine Hatch Cambridge
32 William Healy Natick
35 Clark Leonard Hull New Haven, Conn.
33 Walter Samuel Hunter Providence, R I.
28 Albert Cornelius Knudson Cambridge
32 Karl Spencer Lashley Orange Park, Fla.
29 Clarence Irving Lewis Lexington
42 Richard Peter McKeon Chicago, Ill.
35 Henry Alexander Murray, Jr. Boston
32 Arthur Darby Nock Cambridge
28 Johnson O Connor Boston
17 Charles Edwards Park Boston
33 Carroll Cornelius Pratt New Brunswick, N. J.
30 James Hugh Ryan. . Omaha, Neb.
31 Henry Knox Sherrill . Boston
27 Willard Learoyd Sperry. Cambridge
29 Russell Henry Stafford Brookline
34 Lewis Madison Terman . Belmont
34 Edward Lee Thorndike Montrose, N. Y.
37 Louis Leon Thurstone . ... Chicago, Ill.

28 Henry Bradford Washburn. Cambridge
17 John Broadus Watson . New York, N. Y.
33 Frederic Lyman Wells Newton Highlands
35 Robert Sessions Woodworth New York, N. Y.
15 Robert Mearns Yerkes . New Haven, Conn

CLASS IV, SECTION II—*History, Archaeology, and Anthropology*—43

41 Warren Ortman Ault . Waban
28 James Phinney Baxter, 3d Williamstown
23 Carl Lotus Becker Ithaca, N Y
27 Robert Pierpont Blake Cambridge
39 Crane Brinton Cambridge
42 Henry Joel Cadbury . Cambridge
(25) 32 William Brooks Cabot Boston
34 Clarence Gordon Campbell New York, N. Y
12 George Henry Chase . Cambridge
44 William Bell Dinsmoor New York, N. Y
21 Max Farrand Bar Harbor, Me
21 William Scott Ferguson Cambridge
38 Allyn Bailey Forbes Cambridge
33 Henry Thatcher Fowler Harmony, R I
38 Claude Moore Fuess Andover
18 Evarts Boutell Greene Croton-on-Hudson, N Y
43 Hugh O'Neill Hencken Chestnut Hill
14 Bert Hodge Hill Athens, Greece
27 Earnest Albert Hooton Cambridge
33 Halford Lancaster Hoskins Medford
44 Clyde Kay Maben Kluckhohn Cambridge
12 Alfred Louis Kroeber Berkeley, Cal
15 Kirsopp Lake . So Pasadena, Cal
44 Ambrose Lansing New York, N. Y
22 George La Piana Cambridge
32 Waldo Gifford Leland Washington, D. C
41 William E. Lingelbach Philadelphia, Pa
20 Charles Howard McIlwain . Belmont
14 Roger Bigelow Merriman . Cambridge
38 Stewart Mitchell Gloucester
15 Samuel Eliot Morison .Canton
34 Robert Henry Pfeiffer Cambridge
34 David Moore Robinson Baltimore, Md.
23 Michael Ivanovich Rostovtzeff New Haven, Conn.
27 George Sarton . . Cambridge
38 Bernadotte Everly Schmitt . Chicago, Ill.
36 Donald Scott. . Cambridge
34 Theodore Leslie Shear Princeton, N J
26 Herbert Joseph Spinden Brooklyn, N Y.
32 Charles Holt Taylor Cambridge
11 Alfred Marston Tozzer Cambridge
39 Henry Rouse Viets Dedham
20 Clark Wissler New York, N. Y.

CLASS IV, SECTION III—*Philology*—55

33 William Nickerson Bates. . Philadelphia, Pa.
35 Charles Henry Beeson. Chicago, Ill.
33 Campbell Bonner Ann Arbor, Mich.
35 Robert Johnson Bonner . Chicago, Ill.
41 Giuseppe Antonio Borgese Chicago, Ill.
21 Carl Darling Buck . . Chicago, Ill.
18 Edward Capps. . Princeton, N. J.
20 Walter Eugene Clark Cambridge
32 Ronald Salmon Crane Chicago, Ill.
32 Morris William Croll Princeton, N. J.
44 Henry Grattan Doyle Washington, D. C.
20 Franklin Edgerton . New Haven, Conn
40 Serge Elisséeff Cambridge
14 Jeremiah Denis Mathias Ford Cambridge
30 James Geddes, Jr. Brookline
16 Louis Herbert Gray New York, N Y
25 William Chase Greene Cambridge
13 Charles Burton Gulick Cambridge
34 Austin Morris Harmon New Haven, Conn
31 Raymond Dexter Havens Baltimore, Md
38 Richmond Laurin Hawkins Cambridge
18 George Lincoln Hendrickson New Haven, Conn.
17 William Guild Howard Cambridge
40 Werner Wilhelm Jaeger Watertown
32 (Ralph) Hayward Keniston Ann Harbor, Mich
34 Roland Grubb Kent Wynnewood, Pa
33 Hans Kurath Providence, R I
39 Henry Carrington Lancaster Baltimore, Md
32 Ernest Felix Langley Cambridge
33 Ivan Mortimer Linforth Berkeley, Cal
44 Elias Avery Lowe Princeton, N. J.
11 Albert Matthews Boston
35 Benjamin Dean Meritt Princeton, N. J
43 Perry Gilbert Eddy Miller Cambridge
28 William Albert Nitze Los Angeles, Cal.
32 George Rapall Noyes Berkeley, Cal
34 William Abbott Oldfather Urbana, Ill
33 Howard Rollin Patch Northampton
32 Arthur Stanley Pease Cambridge
11 Fred Norris Robinson Cambridge
38 Hyder Edward Rollins Cambridge
31 Robert Kilburn Root Princeton, N. J
35 Henry Arthur Sanders Ann Arbor, Mich
18 Rudolph Schevill Berkeley, Cal
43 Jean Joseph Seznec Cambridge
32 Horatio Elwin Smith. New York, N Y.
39 John Strong Perry Tatlock Berkeley, Cal
32 William Thomson So Lincoln
11 Charles Cutler Torrey New Haven, Conn
44 La Rue Van Hook New York, N Y
33 George Benson Weston Cambridge
30 Ernest Hatch Wilkins Oberlin, Ohio
33 Harry Austryn Wolfson Cambridge
39 William Hoyt Worrell Ann Arbor, Mich

CLASS IV, SECTION IV—*The Fine Arts and Belles Lettres*—50

43 Leonard Bacon Peace Dale, R. I
26 Frank Weston Benson Salem
32 (William) Welles Bosworth Locust Valley, N Y.
42 John Nash Douglas Bush Cambridge
33 John Alden Carpenter Chicago, Ill
43 Willa Sibert Cather New York, N. Y.
32 Chalmers Dancy Clifton New York, N Y
32 Kenneth John Conant Cambridge
34 Charles Jay Connick Newtonville
29 Charles Townsend Copeland . Cambridge

34 Samuel Foster Damon	Providence, R. I.
41 Archibald Thompson Davison	Lincoln
32 George Harold Edgell	Cambridge
21 William Emerson	Cambridge
30 John Erskine	New York, N Y
18 Edward Waldo Forbes	Cambridge
31 Robert Frost	South Shaftsbury, Vt
27 Wallace Goodrich	Manchester
44 Walter Gropius	Lincoln
36 William Clifford Heilman	Cambridge
29 Edward Burlingame Hill	Cambridge
31 Robert Silliman Hillyer	Cambridge
27 Charles Hopkinson	Manchester
12 Mark Antony DeWolfe Howe	Boston
38 Joseph Hudnut	Boston
18 Archer Milton Huntington	New York, N Y
31 Henry James	New York, N Y.
38 Howard Mumford Jones	Cambridge
42 Otto Kinkeldey	Ithaca, N Y
33 Leo Rich Lewis	Tufts College
21 John Livingston Lowes	Cambridge
21 Charles Donagh Maginnis	Brookline
31 Paul Manship	New York, N. Y
31 Daniel Gregory Mason	New York, N Y
31 Frank Jewett Mather	Washington Crossing, Pa
44 Charles Rufus Morey	Princeton, N J
31 Kenneth Ballard Murdock	Boston
14 William Allan Neilson	Falls Village, Conn
28 Curtis Hidden Page	Gilmanton, N H
(24) 32 Anthony John Philpott	Arlington
41 Walter Hamor Piston, Jr	Belmont
21 Chandler Rathfon Post	Cambridge
22 Paul Joseph Sachs	Cambridge
14 Ellery Sedgwick	Boston
19 Henry Dwight Sedgwick	Dedham
33 David Stanley Smith	Woodbridge, Conn
39 Francis Henry Taylor	New York, N. Y
43 Randall Thompson	Charlottesville, Va
44 Karl Victor	Cambridge
39 Karl Ephraim Weston	Williamstown
44 Herbert Eustis Winlock	New York, N Y
22 Charles Henry Conrad Wright	Cambridge

FELLOWS EMERITI—5

Class IV, Section I—1

21 William Ernest Hocking	Madison, N H

Class IV, Section III—2

15 Carl Newell Jackson	Snowville, N H
13 Edward Kennard Rand	Cambridge

Class IV, Section IV—2

29 Edward Burlingame Hill	Cambridge
21 John Livingston Lowes	Cambridge

FOREIGN HONORARY MEMBERS—119

(Number limited to one hundred and thirty)

CLASS I—Mathematical and Physical Sciences—27

Section I—*Mathematics and Astronomy*—8

39 Arnaud Denjoy — Paris
22 Sir Arthur Stanley Eddington, Cambridge, England
34 Ronald Aylmer Fisher — Harpenden, Herts
20 Jacques Salomon Hadamard — Princeton, N J
21 Godfrey Harold Hardy — Cambridge, England
27 Ejnar Hertzsprung — Leyden
15 Charles Jean de la Vallee Poussin — Louvain
29 Hermann Weyl — Princeton, N J

Class I, Section II—*Physics*—6

29 Vilhelm Frimann Koren Bjerknes — Oslo
24 Albert Einstein — Princeton, N J
29 James Franck — Chicago, Ill
29 Abram F Joffé — Leningrad
28 Freidrich Paschen — Charlottenburg
14 Max Planck — Berlin

Class I, Section III—*Chemistry*—7

29 Johannes N Bronsted — Copenhagen
27 Peter Debye — Ithaca, N. Y.
33 Jaroslav Heyrovsky — Prague
33 Fritz Paneth — Durham
38 Leopold Ruzicka — Zurich
38 Nevil Vincent Sidgwick — Oxford
29 Heinrich Wieland — Munich

Class I, Section IV—*Technology and Engineering*—6

36 Edward Victor Appleton — London
34 Luigi Lombardi — Rome
29 Ludwig Prandtl — Gottingen
29 Emil Probst — Oxford
29 Aurel Stodola — Zürich
31 Karl Willy Wagner — Berlin

CLASS II—Natural and Physiological Sciences—29

Section I—*Geology, Mineralogy, and Physics of the Globe*—7

36 Raoul Blanchard — Grenoble, France
29 Léon William Collet — Geneva
34 Arthur Holmes — Durham
22 Emmanuel de Margerie — Paris
21 Gustaf Adolf Frederik Molengraaff — Delft
44 Ezequiel Ordoñez — Mexico, D F
18 Sir William Napier Shaw — London

Class II, Section II—*Botany*—6

32 Frederick Orpen Bower — Ripon
31 Ludwig Diels — Berlin
32 Kingo Miyabe — Sapporo, Japan
42 Lorenzo Raimundo Parodi — Buenos Aires
29 Otto Renner — Jena
35 Sir William Wright Smith — Edinburgh

Class II, Section III—*Zoology and Physiology*—9

38 Edgar Douglas Adrian — Cambridge, England
38 Sir Joseph Barcroft — Cambridge, England
20 Maurice Caullery — Paris
38 Emmanuel Fauré-Frémiet — Paris
34 Archibald Vivian Hill — London
41 Bernado Alberto Houssay — Buenos Aires
31 August Krogh — Copenhagen
30 Louis Édouard Lapicque — Paris
28 Sir D'Arcy Wentworth Thompson — St Andrews

Class II, Section IV—*Medicine and Surgery*—7

18 Sir Thomas Barlow, Bart — London
39 Sir Aldo Castellani — Rome
27 Sir Henry Hallett Dale — London
33 Sir Arthur Keith — London
28 Mikinosuke Miyajima — Tokyo
18 Sir Charles Scott Sherrington — Ipswich, England
36 (Jean) Hyacinthe Vincent — Paris

CLASS III—The Social Arts—33

Section I—*Jurisprudence*—13

38 William Warwick Buckland — Cambridge, England
38 Mircea Djuvara — Bucharest
27 Léon Duguit — Bordeaux
33 François Geny — Nancy
38 Arthur Lehman Goodhart — Oxford
39 Wilfrid Arthur Greene, Baron Greene — London
33 Hans Kelsen — Berkeley, Cal
38 Rt. Hon. Lord Macmillan — London
33 Juljusz Makarewicz — Lwów
33 Rudolph Stammler — Wernigerode a. H
33 Giorgio Del Vecchio — Rome
38 Rt. Hon Lord Wright. — London
38 John C. H. Wu — Hong Kong

SECTION II—*Government, International Law, and Diplomacy*—4

38	Dionisio Anzilotti	Rome
32	Paul Claudel	Paris
32	Hu Shih	New York, N. Y.
38	Kenzo Takayanagi	Tokyo

SECTION III—*Economics and Sociology*—12

32	Arthur Lyon Bowley	Haslemere, Surrey
34	Gustav Cassel	Djursholm, Sweden
39	Henry Clay	Kenley, Surrey
44	Daniel Cosío Villegas	Mexico, D F.
35	Luigi Einaudi	Turin
32	Ralph George Hawtrey	London
35	John Maynard Keynes, Baron Keynes	Cambridge, England
35	René Maunier	Paris
28	Arthur Cecil Pigou	Cambridge, England
32	Charles Rist	Fraisses (Loire)
35	S Rudolph Steinmetz	Amsterdam
34	Peter B Struve	Belgrade

SECTION IV—*Administration and Affairs*—3

33	Gösta A Bagge	Stockholm
38	Heinrich Brüning	Cambridge, Mass
38	B. Seebohm Rowntree	North Dean, Bucks

CLASS IV—THE HUMANITIES—31

SECTION I—*Theology, Philosophy, and Psychology*—7

36	Miguel Asín y Palacios	Madrid
28	Benedetto Croce	Naples
29	Étienne Gilson	Melun
28	Edmund Husserl	Freiburg i B.
32	Pierre Janet	Paris
28	Wolfgang Köhler	Swarthmore, Pa.
37	Henri Piéron	Paris

SECTION II—*History, Archaeology, and Anthropology*—6

33	Rafael Altamira y Crevea	Madrid
36	Marcel Aubert	Paris
29	Godfrey R Benson, Baron Charnwood	London
33	Friedrich Meinecke	Berlin-Dahlem
40	Martin Persson Nilsson	Lund
31	George Macaulay Trevelyan	Cambridge, England

SECTION III—*Philology*—7

44	Amado Alonso	Buenos Aires
09	Hermann Georg Jacobi	Bonn
36	Paul Kretschmer	Vienna
32	Paul Mazon	Paris
[12] 28	Hanns Oertel	Munich
17	Ramón Menéndez Pidal	Madrid
32	Frederick William Thomas	Oxford

SECTION IV—*The Fine Arts and Belles Lettres*—11

40	Fernand Baldensperger	Los Angeles, Cal
30	Alfredo Casella	Rome
23	Henry Guy	Grenoble
29	Paul Hazard	Paris
40	Paul Hindemith	New Haven, Conn
34	Serge Koussevitzky	Boston
27	Gilbert Murray	Oxford
31	Edgar Allison Peers	Liverpool
27	Henri Rabaud	Paris
41	Jan Sibelius	Helsinki
40	Igor Stravinsky	Paris

ALPHABETICAL INDEX TO LISTS OF MEMBERS

The letters F, FE and FHM refer to the lists of Fellows, Fellows Emeriti and Foreign Honorary Members, respectively. The class and section are indicated by the numerals following

STATUTES AND STANDING VOTES.

STATUTES.

Adopted November 8, 1911 *amended May* 8, 1912, *January* 8, *and May* 14, 1913, *April* 14, 1915, *April* 12, 1916, *April* 10, 1918, *May* 14, 1919, *February* 8, *April* 12, *and December* 13, 1922, *February* 14, *March* 14, *and October* 10, 1923, *March* 10, 1926, *May* 9, 1928, *April* 8 *and November* 11, 1931, *April* 12, 1933, *February* 14, 1934, *December* 14, 1938, *January* 11, *April* 12, 1939, *May* 8, 1940, *May* 14, 1941, *November* 18, 1942, *and January* 12, 1944.

CHAPTER I

THE CORPORATE SEAL.

ARTICLE 1. The Corporate Seal of the Academy shall be as here depicted:

ARTICLE 2. The Recording Secretary shall have the custody of the Corporate Seal.

See Chap. v, art. 3; chap vi, art 2.

CHAPTER II.

FELLOWS AND FOREIGN HONORARY MEMBERS AND DUES.

ARTICLE 1. The Academy shall consist of Fellows, elected from the citizens or residents of the United States of America, Fellows Emeriti, and Foreign Honorary Members They are arranged in four Classes, according to the Arts and Sciences in which they are severally proficient, and each Class shall be divided into four Sections, namely:

CLASS I *The Mathematical and Physical Sciences*

- Section 1 Mathematics and Astronomy
- Section 2 Physics
- Section 3 Chemistry
- Section 4 Technology and Engineering

CLASS II *The Natural and Physiological Sciences*

- Section 1. Geology, Mineralogy, and Physics of the Globe
- Section 2 Botany
- Section 3. Zoology and Physiology
- Section 4 Medicine and Surgery

CLASS III. *The Social Arts*

- Section 1. Jurisprudence
- Section 2 Government, International Law, and Diplomacy
- Section 3. Economics and Sociology
- Section 4 Administration and Affairs

CLASS IV *The Humanities*

- Section 1 Theology, Philosophy, and Psychology
- Section 2 History, Archæology, and Anthropology
- Section 3 Philology
- Section 4. The Fine Arts and Belles Lettres

ARTICLE 2. The number of Fellows shall not exceed Eight hundred, of whom not more than Six hundred shall be residents of Massachusetts, nor shall there be more than Two hundred and twenty in any one Class.

Fellows of the Academy on retiring from their academic or other regular duties may, if they so desire and with the approval of the Council, be

transferred to the status of Fellows Emeriti. Fellows Emeriti shall be exempt from the payment of dues and may not hold office in the Academy, but shall have all the other privileges of Fellowship In the published lists of the membership of the Academy, Fellows Emeriti shall be separately classified, and shall be outside the statutory limit set on the number of Fellows

ARTICLE 3. The number of Foreign Honorary Members shall not exceed One hundred and thirty. They shall be chosen from among citizens of foreign countries most eminent for their discoveries and attainments in any of the Classes above enumerated There shall not be more than Thirty-five in any one Class

ARTICLE 4. If any person, after being notified of his election as Fellow, shall neglect for six months to accept in writing, or, if a Fellow resident within fifty miles of Boston shall neglect to pay his Admission Fee, his election shall be void; and if any Fellow resident within fifty miles of Boston shall neglect to pay his Annual Dues for six months after they are due, provided his attention shall have been called to this Article of the Statutes in the meantime, he shall cease to be a Fellow, but the Council may suspend the provisions of this Article for a reasonable time.

With the previous consent of the Council, the Treasurer may dispense (*sub silentio*) with the payment of the Admission Fee or of the Annual Dues or both whenever he shall deem it advisable. In the case of officers of the Army or Navy who are out of the Commonwealth on duty, payment of the Annual Dues may be waived during such absence if continued during the whole financial year and if notification of such expected absence be sent to the Treasurer. Upon similar notification to the Treasurer, similar exemption may be accorded to Fellows subject to Annual Dues, who may temporarily remove their residence for at least two years to a place more than fifty miles from Boston.

If any person elected a Foreign Honorary Member shall neglect for six months after being notified of his election to accept in writing, his election shall be void.

See Chap. vii, art 2.

ARTICLE 5. Every Fellow resident within fifty miles of Boston hereafter elected shall pay an Admission Fee of Ten dollars, unless previously as an Associate he has paid an Admission Fee of like amount

Every Fellow resident within fifty miles of Boston shall, and others may, pay such Annual Dues, not exceeding Fifteen dollars, as shall be voted by the Academy at each Annual Meeting, when they shall become due; but any Fellow shall be exempt from the annual payment if, at any time after his admission, he shall pay into the treasury Two hundred dollars in addition to his previous payments. Any Fellow shall also be exempt from Annual Dues who has paid such dues for forty years, or, having attained the age of seventy-five has paid dues for twenty-five years.

Fellows residing more than fifty miles from Boston elected after 1938 shall, and other non-resident Fellows may, pay annual dues of five dollars, which shall entitle them to all privileges of resident Fellows.

All Commutations of the Annual Dues shall be and remain permanently funded, the interest only to be used for current expenses.

Any Fellow not previously subject to Annual Dues who takes up his residence within fifty miles of Boston, shall pay to the treasurer within three months thereafter Annual Dues for the current year, failing which his Fellowship shall cease, but the Council may suspend the provisions of this Article for a reasonable time.

Only Fellows who pay Annual Dues or have commuted them may hold office in the Academy or serve on the Standing Committees or vote at meetings.

ARTICLE 6. Fellows who pay or have commuted the Annual Dues and Foreign Honorary Members shall be entitled to receive gratis one copy of all numbers of the Proceedings and Memoirs of the Academy which have been issued after their election.

See Chap. xi, art 2.

ARTICLE 7. Diplomas signed by the President and the Vice-President of the Class to which the member belongs, and countersigned by the

Secretaries, shall be given to Foreign Honorary Members and to Fellows.

ARTICLE 8. If, in the opinion of a majority of the entire Council, any Fellow or Foreign Honorary Member shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his membership; and if three-fourths of the Fellows present, out of a total attendance of not less than fifty at a Stated Meeting, or at a Special Meeting called for the purpose, shall adopt this recommendation, his name shall be stricken from the Roll.

See Chap. iii, chap vi, art. 1; chap. x, art 1; chap. xi, art. 2.

CHAPTER III.

ELECTION OF FELLOWS AND FOREIGN HONORARY MEMBERS.

The procedure in the election of Fellows and Foreign Honorary Members shall be as follows:

Nominations to Fellowship or Foreign Honorary Membership in any section must be signed by two Fellows of that Section, or by three Fellows of any Section, and sent to the Corresponding Secretary accompanied by a statement of the qualifications of the nominee and brief biographical data.

Notice shall be sent to every Fellow not later than the fifteenth of January in each year, reminding him that all nominations must be in the hands of the Corresponding Secretary before the first of February following.

The Corresponding Secretary shall, on the second of February, transmit to the several Vice-Presidents the nominations for Fellows and Foreign Honorary Members in their respective classes. Each Class Committee shall, before the sixteenth of February, consider the nominations, and may add others for the purpose of securing proper membership in the Academy, to the end that those in the country of highest distinction in their several classes may be Fellows.

A list of the nominees, giving a brief account of each, with the names of the nominators, shall be sent to every Fellow with a request that he return the list with such confidential comments and indications of preference as he may choose to make.

All the nominations, with any comments thereon and with expressions of preference on the part of the Fellows, shall be referred to the appropriate Class Committees, which shall canvass them, and report their recommendations in writing to the Council before the Stated Meeting of the Academy in April.

Elections of Fellows and Foreign Honorary Members shall be made by the Council before the Annual Meeting in May, and announced at that meeting.

Persons nominated in any year, but not elected, may be carried over to the list of nominees for the next year at the discretion of the Council, but shall not be further continued unless renominated.

See Chap ii; chap. vi, art 1, chap. x, art 1.

CHAPTER IV.

OFFICERS.

ARTICLE 1. The Officers of the Academy shall be a President (who shall be Chairman of the Council), four Vice-Presidents (one from each Class), a Corresponding Secretary (who shall be Secretary of the Council), a Recording Secretary, a Treasurer, a Librarian, and an Editor, all of whom shall be elected by ballot at the Annual Meeting, and shall hold their respective offices for one year, and until others are duly chosen and installed.

There shall be also sixteen Councillors, one from each Section of each Class. At each Annual Meeting four Councillors, one from each Class, shall be elected by ballot to serve for the full term of four years and until others are duly chosen and installed. The same Fellows shall not be eligible for two successive terms

The Councillors, with the officers previously named, and the Chairmen of the House Committee and the Committee on Resources and Policy, *ex officiis*, shall constitute the Council.

See Chap. xi, art 1

ARTICLE 2 If any officer be unable, through death, absence, or disability, to fulfill the duties of his office, or if he shall resign, his place may be

filled by the Council in its discretion for any part or the whole of the unexpired term.

ARTICLE 3. At the Stated Meeting in March, the President shall appoint a Nominating Committee of four Fellows having the right to vote, one from each Class. This Committee shall prepare a list of nominees for the several offices to be filled, and for the Standing Committees, and file it with the Recording Secretary not later than four weeks before the Annual Meeting.

See Chap vi, art 2.

ARTICLE 4. Independent nominations for any office, if signed by at least twenty Fellows having the right to vote, and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call therefor, and shall be mailed to all the Fellows having the right to vote.

See Chap vi, art 2.

ARTICLE 5. The Recording Secretary shall prepare for use in voting at the Annual Meeting a ballot containing the names of all persons duly nominated for office.

CHAPTER V.

THE PRESIDENT.

ARTICLE 1 The President, or in his absence the senior Vice-President present (seniority to be determined by length of continuous Fellowship in the Academy), shall preside at all meetings of the Academy. In the absence of all these officers, a Chairman of the meeting shall be chosen by ballot.

ARTICLE 2. Unless otherwise ordered, all Committees which are not elected by ballot shall be appointed by the presiding officer.

ARTICLE 3. Any deed or writing to which the Corporate Seal is to be affixed, except leases of real estate, shall be executed in the name of the Academy by the President or, in the event of his death, absence, or inability, by one of the Vice-Presidents, when thereto duly authorized.

See Chap. ii, art. 7; chap. iv, art 1, 3; chap. vi, art. 2, chap. vii, art. 1; chap. x, art. 6, chap. xi, art. 1, 2; chap. xii, art. 1

CHAPTER VI.

THE SECRETARIES.

ARTICLE 1. The Corresponding Secretary shall conduct the correspondence of the Academy and of the Council, recording or making an entry of all letters written in its name, and preserving for the files all official papers which may be received. At each meeting of the Council he shall present the communications addressed to the Academy which have been received since the previous meeting, and at the next meeting of the Academy he shall present such as the Council may determine.

He shall notify all persons who may be elected Fellows or Foreign Honorary Members, send to each a copy of the Statutes, and on their acceptance issue the proper Diploma He shall also notify all meetings of the Council, and in case of the death, absence, or inability of the Recording Secretary he shall notify all meeting of the Academy.

Under the direction of the Council, he shall keep a List of the Fellows and Foreign Honorary Members, arranged in their several Classes and Sections. It shall be printed annually and issued as of the first day of July.

See Chap ii, art. 7, chap iii, chap iv, art. 1, chap. x, art 6, chap xi, art 1, chap xii, art. 1

ARTICLE 2. The Recording Secretary shall have the custody of the Charter, Corporate Seal, Archives, Statute-Book, Journals, and all literary papers belonging to the Academy.

Fellows borrowing such papers or documents shall receipt for them to their custodian.

The Recording Secretary shall attend the meetings of the Academy and keep a faithful record of the proceedings with the names of the Fellows present; and after each meeting is duly opened, he shall read the record of the preceding meeting.

He shall notify the meetings of the Academy to each Fellow and by mail at least seven days beforehand, and in his discretion may also cause the meetings to be advertised; he shall apprise Officers and Committees of their election or appointment, and inform the Treasurer of appropriations of money voted by the Academy.

After all elections, he shall insert in the Records

the names of the Fellows by whom the successful nominees were proposed.

He shall send the Report of the Nominating Committee in print to every Fellow having the right to vote at least three weeks before the Annual Meeting.

See Chap. IV, art. 3

In the absence of the President and of the Vice-President he shall, if present, call the meeting to order, and preside until a Chairman is chosen.

See Chap. i, chap ii, art 7, chap iv, art 3, 4, 5; chap x, art 6, chap xi, art 1, 2, chap xii, art. 1, 3.

ARTICLE 3. The Secretaries, with the Editor, shall have authority to publish such of the records of the meetings of the Academy as may seem to them likely to promote its interests.

CHAPTER VII.

THE TREASURER AND THE TREASURY.

ARTICLE 1. The Treasurer shall collect all money due or payable to the Aacedmy and all gifts or bequests made to it He shall pay all bills due and payable by the Academy when approved by the proper officers. He shall sign all leases of real estate in the name of the Academy. He shall be the official custodian of all bonds, stocks and other securities and, with the written approval of any one member of the Committee on Finance, he shall have full authority to sell and transfer, invest and reinvest from time to time in such manner and upon such terms as shall to him seem best, the whole or any part of the personal property of the said Academy.

He shall keep a faithful account of all receipts and expenditures, submit his accounts annually to the Auditing Committee, and render them at the expiration of his term of office, or whenever required to do so by the Academy or the Council.

He shall keep separate accounts of the income of the Rumford Fund, and of all other special Funds, and of the Appropriation thereof, and render them annually.

His accounts shall always be open to the inspection of the Council.

ARTICLE 2. He shall report annually to the Council at its March meeting on the expected income of the various Funds and from all other sources during the ensuing financial year. He shall also report the names of all Fellows who may be then delinquent in the payment of their Annual Dues.

ARTICLE 3. He shall give such security for the trust reposed in him as the Academy may require.

ARTICLE 4. With the approval of a majority of the Committee on Finance, he may appoint an Assistant Treasurer to perform his duties, for whose acts, as such assistant, he shall be responsible; or, with like approval and responsibility, he may employ any Trust Company doing business in Boston as his agent for the same purpose, the compensation of such Assistant Treasurer or agent to be fixed by the Committee on Finance and paid from the Funds of the Academy.

ARTICLE 5. At the Annual Meeting he shall report in print all his official doings for the preceding year, stating the amount and condition of all the property of the Academy entrusted to him, and the character of the investments.

ARTICLE 6. The Financial Year of the Academy shall begin with the first day of April

ARTICLE 7. No person or committee shall incur any debt or liability in the name of the Academy, unless in accordance with a previous vote and appropriation therefor by the Academy or the Council, or sell or otherwise dispose of any property of the Academy, except cash or invested funds, without previous consent and approval of the Council.

See Chap ii, art 4, 5, chap vi, art 2, chap x, art 6, chap. xi, art 1, 2, 3, chap xii, art 1

CHAPTER VIII.

THE LIBRARIAN AND THE LIBRARY.

ARTICLE 1. The Librarian shall have charge of the printed books, keep a correct catalogue

thereof, and provide for their delivery from the Library.

At the Annual Meeting, as Chairman of the Committee on the Library, he shall make a Report on its condition.

Article 2 In conjunction with the Committee on the Library he shall have authority to expend such sums as may be appropriated by the Academy for the purchase of books, periodicals, etc., and for defraying other necessary expenses connected with the Library.

Article 3. All books procured from the income of the Rumford Fund or of other special Funds shall contain a book-plate expressing the fact.

Article 4. Books taken from the Library shall be receipted for to the Librarian or his assistant.

Article 5. Books shall be returned in good order, regard being had to necessary wear with good usage. If any book shall be lost or injured, the Fellow to whom it stands charged shall replace it by a new volume or by a new set, if it belongs to a set, or pay the current price thereof to the Librarian, whereupon the the remainder of the set, if any, shall be delivered to the Fellow so paying, unless such remainder be valuable by reason of association.

Article 6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

Article 7. The Librarian shall have the custody of the Publications of the Academy. With the advice and consent of the President, he may effect exchanges with other associations.

See Chap. ii, art. 6; chap. xi, art. 1, 2.

CHAPTER IX.

The Editor and the Publications.

Article 1. The Editor shall have charge of the conduct through the press of the Proceedings and the Memoirs, and all correspondence relative thereto, and shall have power to fix the price at which individual numbers of the Proceedings and Memoirs are sold.

The Editor shall select as Assocaite Editor one member of the Committee of Publication, and the Associate Editor shall assist the Editor in the duties of his office in such way as the two shall find most convenient.

Article 2. In conjunction with the Committee of Publication, the Editor shall have authority to expend such sums as may be appropriated by the Academy for printing the publications and for defraying other expenses therewith connected.

Article 3. All publications which are financed in whole or in part from the income of the Rumford Fund or from the income of other special funds, and all publications of work done with the aid of the Rumford Fund or other special funds, shall contain a conspicuous statement of this fact.

Article 4. Two hundred extra copies of each paper printed in the Proceedings or Memoirs shall be placed at the disposal of the author without charge.

If, on account of the number of communications offered for publication, it shall be necessary to decline for publication communications otherwise acceptable, members of the Academy shall be given preference in each of the several Classes over non-members; but whenever it shall be necessary to exercise this preference, the Editor shall inform the Council of the fact.

See Chap iv, art 1, chap vi, art. 3; chap. x, art. 6; chap. xi, art. 2, sect. 5.

CHAPTER X.

The Council.

Article 1. The Council shall exercise a discreet supervision over all nominations and elections to membership, and in general supervise all the affairs of the Academy not explicitly reserved to the Academy as a whole or entrusted by it or by the Statutes to standing or special committees.

It shall consider all nominations duly sent to it by any Class Committee, and act upon them in accordance with the provisions of Chapter III.

With the consent of the Fellow interested, it shall have power to make transfers between the several Sections, reporting its action to the Academy.

See Chap. iii, chap. xi, art. 1.

ARTICLE 2. Nine members shall constitute a quorum.

ARTICLE 3. It shall establish rules and regulations for the transaction of its business, and provide all printed and engraved blanks and books of record.

ARTICLE 4. It shall act upon all resignations of officers, and all resignations and forfeitures of Fellowship; and cause the Statutes to be faithfully executed.

It shall appoint all agents and subordinates not otherwise provided for by the Statutes, prescribe their duties, and fix their compensation. They shall hold their respective positions during the pleasure of the Council.

ARTICLE 5. It may appoint, for terms not exceeding one year, and prescribe the functions of, such committees of its number, or of the Fellows of the Academy, as it may deem expedient, to facilitate the administration of the affairs of the Academy or to promote its interests.

ARTICLE 6. At its March meeting it shall receive reports from the President, the Secretaries, the Treasurer, and the Standing Committees, on the appropriations severally needed for the ensuing financial year. At the same meeting the Treasurer shall report on the expected income of the various Funds and from all other sources during the same year.

A report from the Council shall be submitted to the Academy, for action, at the March meeting, recommending the appropriation which in the opinion of the Council should be made.

On the recommendation of the Council, special appropriations may be made at any Stated Meeting of the Aacdemy, or at a Special Meeting called for the purpose.

See Chap. xi, art 3.

ARTICLE 7. It shall report at every meeting of the Academy such business as it may deem advisable to present.

See Chap ii, art. 4, 5, 8, chap. iv, art. 1, 2, chap. vi, art. 1, chap vii, art 1, chap xii, art. 1, 4.

CHAPTER XI.

STANDING COMMITTEES

ARTICLE 1. The Class Committee of each Class shall consist of the Vice-President, who shall be chairman, and the four Councillors of the Class, together with such other officer or officers annually elected as may belong to the Class. It shall consider nominations to Fellowship in its own Class, and report in writing to the Council such as may receive at a Class Committee Meeting a majority of the votes cast, provided at least three shall have been in the affirmative.

See Chap iii.

ARTICLE 2. At the Annual Meeting the following Standing Committees shall be elected by ballot to serve for the ensuing year.

(i) *The Committee on Finance,* to consist of four Fellows, who shall have general oversight of the funds and investments of the Academy.

See Chap iv, art 3, chap vii, art. 1, 4; chap x, art. 6

(ii) *The Committee on Policy and Resources* to consist of five Fellows and the President, *ex officio,* one of the five elected members to be elected each year to serve for a term of five years, except that the five elected in 1939 shall be elected for terms of one, two, three, four, and five years respectively, the Committee to concern itself with procuring funds for the Academy, to study the activities and needs of the Academy, and to recommend, for the approval of the Council, means by which the functions and purposes of the Academy may best be fulfilled.

(iii) *The Rumford Committee,* to consist of seven Fellows, who shall report to the Academy on all applications and claims for the Rumford Premium. It alone shall authorize the purchase of books, publications and apparatus at the

charge of the income from the Rumford Fund, and generally shall see to the proper execution of the trust

See Chap iv, art. 3, chap x, art 6.

(iv) *The Cyrus Moors Warren Committee*, to consist of seven Fellows, who shall consider all applications for appropriations from the income of the Cyrus Moors Warren Fund, and generally shall see to the proper execution of the trust.

See Chap iv, art 3, chap x, art. 6

(v) *The Committee of Publication*, to consist of the Editor, *ex officio*, as Chairman, and four other Fellows, one from each Class, to whom all communications submitted to the Academy for publication shall be referred, and to whom the printing of the Proceedings and the Memoirs shall be entrusted

It shall fix the price at which volumes of the publications shall be sold, but Fellows may be supplied at half price with volumes and with single publications which they are not entitled to receive gratis.

It shall determine when the pressure of material offered for publication makes it necessary to give preference to members of the Academy as compared with non-members, or to give priority to certain members as compared with others, and to what extent this preference or priority shall be applied in each of the four Classes, to the end that a proper balance of the facilities of publication with respect to subject matter and authors may be maintained.

See Chap. iv, art. 3, chap. vi, art. 1, 3, chap. ix; chap x, art 6

(vi) *The Committee on the Library*, to consist of the Librarian, *ex officio*, as Chairman, and four other Fellows, one from each Class, who shall examine the Library and make an annual report on its condition and management.

See Chap iv, art 3, chap viii, art. 1, 2; chap. x, art 6

(vii) *The House Committee*, to consist of four Fellows, who shall have charge of all expenses connected with the House, including the general expenses of the Academy not specifically assigned to the care of other Committees or Officers.

See Chap. iv, art 1, 3; chap. x, art 6.

(viii) *The Committee on Meetings*, to consist of the President, the Recording Secretary, and four other Fellows, who shall have charge of plans for meetings of the Academy.

See Chap. iv, art. 3, chap x, art 6.

(ix) *The Auditing Committee*, to consist of two Fellows, who shall audit the accounts of the Treasurer, with power to employ an expert and to approve his bill.

See Chap iv, art 3, chap vii, art 1, chap x, art 6

(x) *The Committee on Biographical Notices*, to consist of six Fellows, two to be elected each year, one of them to be a Secretary of the Academy, to see that biographical records of the Fellows and Foreign Honorary Members are provided.

ARTICLE 3. The Standing Committees shall report annually to the Council in March on the appropriations severally needed for the ensuing financial year; and all bills incurred on account of these Committees, within the limits of the several appropriations made by the Academy, shall be approved by their respective Chairmen

In the absence of the Chairman of any Committee, bills may be approved by any member of the Committee whom he shall designate for the purpose.

See Chap. vii, art. 1, 7, chap. x, art. 6

CHAPTER XII.

MEETINGS, COMMUNICATIONS, AND AMENDMENTS

ARTICLE 1. There shall be annually eight Stated Meetings of the Academy, namely, on the second Wednesday of October, November, December, January, February, March, April, and May. Only at these meetings, or at adjournments thereof regularly notified, or at Special Meetings called for the purpose, shall appropriations of money be made or amend-

ments of the Statutes or Standing Votes be effected.

The Stated Meeting in May shall be the Annual Meeting of the Corporation

Special Meetings shall be called by either of the Secretaries at the request of the President, of a Vice-President, of the Council, or of ten Fellows having the right to vote; and notifications thereof shall state the purpose for which the meeting is called

The Council shall have authority, as occasion may demand, to arrange additional meetings and to cancel any of the Statutory meetings, except that meetings for transacting business shall be held as required by the Statutes.

ARTICLE 2. Twenty-five Fellows having the right to vote shall constitute a quorum for the transaction of business at Stated or Special Meetings Eighteen Fellows shall be sufficient to constitute a meeting for literary or scientific communications and discussions.

ARTICLE 3. Upon the request of the presiding officer or the Recording Secretary, any motion or resolution offered at any meeting shall be submitted in writing.

ARTICLE 4 No report of any paper presented at a meeting of the Academy shall be published by any Fellow without the consent of the author; and no report shall in any case be published by any Fellow in a newspaper as an account of the proceedings of the Academy without the previous consent and approval of the Council. The Council, in its discretion, by a duly recorded vote, may delegate its authority in this regard to one or more of its members

ARTICLE 5 Fellows may introduce guests at any of the literary or scientific meetings of the Academy.

ARTICLE 6. The Academy shall not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its Publications.

ARTICLE 7. All proposed Amendments of the Statutes shall be referred to a committee, and on its report, at a subsequent Stated Meeting or at a Special Meeting called for the purpose, two-thirds of the ballots cast, and not less than twenty-five, must be affirmative to effect enactment.

ARTICLE 8 Standing Votes may be passed, amended, or rescinded at a Stated Meeting, or at a Special Meeting called for the purpose, by a vote of two-thirds of the members present They may be suspended by a unanimous vote

See Chap II, art 5, 8, chap III, chap IV, art 3, 4, 5, chap V, art 1, chap VI, art 1, 2, chap X art 7

STANDING VOTES

1. Communications of which notice has been given to either of the Secretaries shall take precedence of those not so notified.

2. Fellows may take from the Library six volumes at any one time, and may retain them for three months, and no longer. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period

3. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy without the leave of the Librarian.

4 Communications offered for publication in the Proceedings or Memoirs of the Academy shall not be accepted for publication before the author either himself or through some agent, shall have informed the Committee on Meetings of his readiness to use such time as the Committee may assign him at such meeting as may be convenient both to him and to the Committee, for the purpose of presenting to the Academy a general statement of the nature and significance of the results contained in his communication.

RUMFORD PREMIUM

In conformity with the terms of the gift of Sir Benjamin Thompson, Count Rumford, of a certain Fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court of Massachusetts for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of the Rumford Fund, as it now exists, at any Annual Meeting, an award of a gold and a silver medal, being together of the intrinsic value of three hundred dollars, as a Premium to the author of any important discovery or useful improvement in light or heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands, preference always being given to such discoveries as, in the opinion of the Academy, shall tend most to promote the good of mankind; and, if the Academy sees fit, to add to such medals, as a further Premium for such discovery and improvement, a sum of money not exceeding three hundred dollars.

PERMANENT SCIENCE FUND

By an Agreement and Declaration of Trust dated Sept 5, 1928, the BOSTON SAFE DEPOSIT AND TRUST COMPANY agrees to accept and hold gifts made to it as Trustee of the PERMANENT SCIENCE FUND and to pay the income to the AMERICAN ACADEMY OF ARTS AND SCIENCES, to be applied to such scientific research "as shall be deemed charitable within the broadest possible construction of that term" in such sciences as Mathematics, Physics, Chemistry, Astronomy, Geology, Geography, Zoology, Botany, Anthropology, Psychology, Sociology and Economy, History and Philology, Engineering, Medicine and Surgery, Agriculture, Manufacture and Commerce, Education and any other science of any nature or description whether or not now known or now recognized as scientific; and may be applied to or through public or private associations, societies or institutions, or to or through one or more individuals.

Disbursements from income are voted by the Council of the Academy upon recommendations from the Committee on the Permanent Science Fund. A brochure comprising the First Decennial Report on the history and activities of this committee and a copy of the Agreement and Declaration of Trust is available on request to the Trustee at 100 Franklin Street, Boston, Mass.

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Proceedings of the American Academy of Arts and Sciences

Vol. 76, No. 1, P. 1–24—February, 1945

THE COMPRESSION OF TWENTY-ONE HALOGEN COMPOUNDS AND ELEVEN OTHER SIMPLE SUBSTANCES TO 100,000 kg/cm²

By P. W. Bridgman

THE COMPRESSION OF SIXTY-ONE SOLID SUBSTANCES TO 25,000 kg/cm², DETERMINED BY A NEW RAPID METHOD

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(Continued from page three of cover)

VOLUME 76

1. BRIDGMAN, P. W.—The Compression of Twenty-one Halogen Compounds and Eleven Other Simple Substances to 100,000 kg/cm², the Compression of Sixty-one Solid Substances to 25,000 kg/cm², Determined by a New Rapid Method. pp. 1–24. February, 1945. $1 00

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Presented Oct 11, 1944 Received Oct 17, 1944

Contents

Introduction

In this paper the method previously used[1] in determining the compressions of seventeen elements to 100,000 kg/cm² is extended to a determination of the twenty-one halogen compounds of sodium, potassium, rubidium, caesium, silver, thallium, and ammonium, of the corresponding seven nitrates, of sulfur, of silver bromate, of metallic lead both in the massive and finely powdered condition, and to a redetermination of the compression of metallic indium.

The measurements on sulfur and all the salts except NH_4NO_3 were made in 1941 and early 1942, and have been waiting since for an opportunity for publication The measurements on NH_4NO_3, lead, and indium were made early in 1944, when opportunity was found to resume measurements. The apparatus had been left untouched in the interval, and on resumption of work functioned at once, with no important alteration in any of the constants, except for one matter to be mentioned presently

In addition to the measurements recorded here, data were also obtained for the compressions of arsenic, and of lead sulfide, selenide, and telluride The frictional resistance to the motion of the piston offered by these hard substances resulted in so great difference between the displacements with increasing and decreasing pressure that it did not seem worth while to subject the measurements to calculation. It can be stated, however, that no new transitions were found in the range above 50,000; the known transitions of the selenide and telluride below 50,000 were again encountered. It will probably be possible to make satisfactory measurements on substances as hard as these by a modification in technique which has been sufficiently used to show its promise. This consists in enclosing the substance in a thin capsule of indium, by which the stress on the outside of the specimen is reduced to an approximate hydrostatic pressure Any measurements by this technique will be reserved for a future communication

Method of Measurement and Calculation

As compared with the previous work already described in full detail, little change was made in the experimental technique A revised method of calculation was adopted, however It will be recalled that the method is a differential one, in which the piston displacement is determined as a function of pressure when the piezometer is filled with the substance under investigation and when filled with gold, it being assumed that the compression of gold is known In any single run the measured piston displacement is a function not only of the pressure prevailing inside the high pressure piezometer, but also of the hydrostatic pressure in the surrounding liquid, of the pressure driving the piston by which this pressure is produced (that is, it is a function of the friction on the ram of the hydraulic press), and of the external pressure applied to the cylinder of the 30,000 apparatus to prevent it from bursting, the effect of this external pressure being to lengthen the 30,000 cylinder and give an apparent component to the displacement of the piston of the 100,000 piezometer. In the previous method of calculation mean values were applied for these various disturbing effects, the corrections being calculated at the extreme points on the basis of the average of many runs and the corrections for intermediate points were determined by linear interpolation. The new method of calculation was considerably more elaborate in that the three corrections were calculated in detail at every point from the various actual readings at that point In general, the new procedure gives lower

values for the volume decrements, the decrease being confined almost entirely to the lower end of the pressure range from 25,000 to 50,000 kg/cm². The presumptive superiority of the new and more elaborate method is established by the fact that the revised method gives better agreement with the previous measurements[2] on the halogen compounds in the common range. These compounds had been previously measured in the range from atmospheric pressure up to 50,000 kg/cm².

A fundamental datum necessary in the calculations is the compression at 25,000 kg/cm², this being the initial pressure of these measurements. The compressions at 25,000 of the halogen compounds had been previously determined, as just mentioned, but no such information was in existence for the nitrates or $AgBrO_3$. Independent measurements were therefore made of the compression of these substances to 25,000 kg/cm² These were made by a new method with a new apparatus which permits rapid measurements of sufficient accuracy. The measurements will be described in the paper[3] immediately following; only the results will be used here.

An improvement has been introduced in the method for determining the compression coefficient of the compressometer which permits its rapid determination, while the compressometer is mounted in the 30,000 apparatus *in situ* ready for the measurements to 100,000. The constant freshly determined by this method was a few per cent lower than in the original determination by the former method several years ago.

The difficulty on resuming measurements referred to at the end of the second paragraph of the introduction was the following A new manipulative trick which much facilitated assembly was adopted on resumption of work; this consisted in holding one of the loose carboloy plattens in position with a minute gob of wax. Many irregular results, including spurious polymorphic transitions, were traced after much time and effort to the account of the wax. At low pressures the wax dissolves in the isopentane by which pressure is transmitted and is carried in solution between the carboloy platten and the grid with which the compressive stress on the piston is measured. The first few thousand atmospheres precipitates this wax in a thin film and freezes it hard; later, when the pressure in the 100,000 piezometer has reached something over 50,000, it is plastically squeezed out in the solid condition, resulting in a spuriously large piston displacement which may simulate a transition. The remedy is scrupulously to free all internal parts of the assembly from any grease or similar substance.

Most of the substances were independently measured with two different piezometers, and the final results are the mean of two runs. Seven different piezometers were used in all, sufficient to permit definite conclusions as to the best grade of carboloy to be used in their construction. Five of these piezometers were made of carboloy no. 905, the grade which was found to be the most successful for the pistons in the measurements of volume changes already published up to 50,000 kg/cm². These five piezometers broke after respectively seven, twelve, seven, six, and five exposures to 100,000 kg/cm². Of the two remaining piezometers, one was of grade no. 55A and the other of grade no. 779. The first of these has at the date of writing survived 55 exposures without fracture and the second 35. The inferiority of grade no. 905 for this purpose is manifest.

Experimental Details

The material used in these measurements was, with few exceptions, the same as that used in previous measurements either of the compressions to 50,000, or in explorations for polymorphic transitions to 50,000,[4] and has already been described in previous papers. My old stock of single crystal NaI was exhausted and the material used here was obtained from the stock room of the Harvard Chemical Laboratory, melted in platinum, and the clear parts of the solidified product selected NH_4Cl and NH_4Br were also fresh material from the stock of the chemical laboratory, used directly without further purification The lead was special lead of 99.9999 per cent purity, as in the previous paper.

There follow now the pertinent details connected with the measurements of the individual substances. In the final results the mean of two independent runs was usually used, and this mean was smoothed so as to give smooth first differences over the entire pressure range from zero up, making a compromise between the present and former determinations in the common range.

In Table I certain data are given which will permit an estimate of the internal consistency of the measurements. This table gives the difference between the volume decrement at 100,000 kg/cm² as determined with either of the

TABLE I

Substance	Difference between mean $\Delta V/V_0$ at 100,000 and individual measurements	Preceding column as fraction of maximum $\Delta V/V_0$	Difference between former $\Delta V/V_0$ at 50,000 and new smoothed result
NaCl	007	033	+ 004
NaBr	007	032	+ 007
NaI	011	041	+ 011
KCl	008	025	+ 004
KBr	014	041	+ 009
KI	010	029	+ 007
RbCl	000	000	+ 015
RbBr	006	017	+ 012
RbI	014	035	+ 016
CsCl	005	021	+ 006
CsBr	007	.026	+ 011
CsI	012	041	+ 005
AgCl	000	000	+ 006
AgBr	005	030	+ 002
AgI	——	——	+ 010
TlCl	003	014	+ 013
TlBr	010	045	+ 014
TlI	011	043	+ 022
NH_4Cl	010	044	+ 008
NH_4Br	010	040	+ 002
NH_4I	017	045	+ 005
S	——	——	+ 012
Pb	001	010	——

two individual piezometers and the mean of the two, both as absolute volume decrement, the volume at atmospheric pressure being taken as unity, and as the fraction which the difference is of the total volume decrement at 100,000. The discrepancy between the two runs was in nearly all cases a maximum at 100,000. Of the substances listed in Table I, measurements were made on AgI with only one piezometer, and although measurements were made on NH_4I with two piezometers, the values obtained with one of them differed so much from the values previously found up to 50,000 that they were discarded and the values listed later in Table IV are based on those obtained with the other piezometer only. The difficulty with NH_4I is to a large extent characteristic of the particular material. This has a large polymorphic transition at a pressure of only a few hundred kilograms; the volume change is so large that it cannot possibly be compensated by the differential compressibility of steel and carboloy, as described in the previous paper, with the result that opportunity is afforded for the capricious trapping of liquid inside the solid resulting in too large compressions. The only way of telling whether this capricious trapping has occurred is by the internal consistency of the results; the discarding of markedly discordant runs would seem to be justified under the conditions.

The agreement of the two runs for lead and indium is, both absolutely and fractionally, better than on the average for the salts, in spite of the fact that the absolute magnitude of the volume decrement is greater for the salts. This is without doubt a consequence of the much greater softness of the two metals, resulting in better agreement between the displacements with increasing and decreasing pressure Measurements were made on both lead and indium in the new apparatus for 25,000 For indium there are previous measurements for comparison[5] both in the range up to 50,000, and also to 100,000, computed by the old method Compared with previous results, the new results are somewhat higher in the neighborhood of 50,000 than the previous results with the 50,000 apparatus, and somewhat lower than the previous results to 100,000 over the entire range. These differences are in the usual direction.

Measurements were made with only one piezometer on each of the nitrates, this was the same piezometer for all The difference between increasing and decreasing pressure was about the same for the nitrates as for the halogen compounds, and the probable accuracy should be about the same. There are no previous measurements on the compression of nitrates to 50,000 for comparison

Table I also lists the discrepancy between the values formerly obtained for the volume decrements at 50,000 and the values now adopted on the basis of the smoothing process over the entire range. This discrepancy is always of the same sign; that is, the value adopted here for the volume decrement is consistently greater at 50,000 than the value previously found from the measurements in the range from atmospheric to 50,000 This indicates a consistent error in the measurements somewhere It seems probable that this consistent error is in the previous measurements to 50,000 and is connected with the fact that we are here dealing with the end of the range. It is always more difficult to get reliable measurements up to the end of the range than in the middle of the range. The sign of the discrepancy is doubtless associated with the friction, which of course is greatest at the top of the range.

The smoothed values adopted for 50,000 are also consistently less than those which would have been indicated by the measurements of this paper for the range 25,000 to 100,000. We are here dealing with the lower end of the pressure range and therefore probably with the inverse of the

effect above. That is, this method tends to give too large volume decrements at the lower end of the range and too small decrements at the upper end of the range. The accuracy of the present measurements is probably greatest in the range from 50,000 to 75,000.

Discussion of Results

The numerical values of the volume decrements, in terms of the volume at atmospheric pressure as unity, are given in Tables II to VI and are plotted in Figures 1 to 4.

No elaborate discussion of these data will be attempted. Qualitatively the behavior in the range from 50,000 to 100,000 is merely a continuation of that already found in the range below 50,000. There is very little tendency for the curves of volume decrement to cross above 50,000, and the few examples of it may be due to experimental error In a general way the atomic contributions to the volume decrements are distinctly recognizable and are the most

TABLE II

$\Delta V/V_0$ of Various Chlorides

Pressure kg/cm²	NaCl	KCl	RbCl	CsCl	AgCl	TlCl	NH_4Cl
10,000	038	048	188[b]	048	021	038	049
20,000	068	084	219	086	040	071	082
30,000	093	223[a]	246	118	058	099	109
40,000	115	244	270	144	074	123	133
50,000	135	262	292	166	090	144	154
60,000	152	277	311	184	104	162	172
70,000	168	290	327	199	117	177	188
80,000	183	302	341	212	129	191	202
90,000	197	312	353	223	140	202	215
100,000	210	321	364	233	165[c]	213	227

[a] Transition at 20,060. $\Delta V/V_0$'s at transition 085 and 197
[b] Transition at 5 000. $\Delta V/V_0$'s at transition 030 and 170
[c] Transition at 90,000. $\Delta V/V_0$'s at transition 140 and 156

TABLE III

$\Delta V/V_0$ of Various Bromides

Pressure kg/cm²	NaBr	KBr	RbBr	CsBr	AgBr	TlBr	NH_4Br
10,000	043	055	188[b]	053	022	043	049
20 000	.078	199[a]	221	095	041	077	088
30,000	107	229	250	130	059	106	120
40 000	132	254	275	160	075	131	147
50,000	153	274	297	186	091	152	170
60,000	171	291	315	208	106	170	189
70,000	186	305	330	227	120	186	205
80,000	199	317	343	243	133	200	219
90,000	211	327	354	258	157[c]	212	232
100,000	222	336	364	272	169	223	244

[a] Transition at 18,400. $\Delta V/V_0$'s at transition 088 and 193
[b] Transition at 4,600. $\Delta V/V_0$'s at transition 033 and 166
[c] Transition at 86,000 $\Delta V/V_0$'s at transition 141 and 152

TABLE IV

$\Delta V/V_0$ of Various Iodides

Pressure kg/cm²	NaI	KI	RbI	CsI	AgI	TlI	NH_4I
10,000	056	065	192[b]	065	189[c]	050	192[d]
20,000	098	197[a]	235	113	209	090	280
30,000	132	230	271	151	228	123	258
40,000	160	257	301	182	246	152	282
50,000	184	279	326	208	263	177	302
60,000	205	298	346	230	278	198	320
70,000	223	314	362	249	292	216	335
80,000	239	327	376	266	305	232	350
90,000	253	338	388	281	317	245	363
100,000	266	348	398	294	328	256	376

[a] Transition at 18,200. $\Delta V/V_0$'s at transition 105 and 190
[b] Transition at 4,050. $\Delta V/V_0$'s at transition 035 and 161
[c] Transition at 3,000. $\Delta V/V_0$'s at transition 011 ± & 174
[d] Transition at 560. $\Delta V/V_0$'s at transition 003 ± & 143

TABLE V

$\Delta V/V_0$ of Various Nitrates

Pressure kg/cm²	$NaNO_3$	KNO_3	$RbNO_3$	$CsNO_3$	$AgNO_3$	$TlNO_3$	NH_4NO_3
10,000	034	138[b]	043	045	044[c]	037	050
20,000	062	169	079	083	077	068	086
30,000	086	196	109	115	103	095	115
40,000	107	219	135	142	126	118	140
50,000	127	238	157	165	146	137	162
60,000	154[a]	255	175	183	162	152	180
70,000	167	268	190	198	176	165	194
80,000	180	280	202	210	188	176	206
90,000	191	289	211	219	198	185	215
100,000	201	297	219	226	206	194	222

[a] Transition at 55,000. $\Delta V/V_0$'s at transition 136 and 147
[b] Transition at 3,650. $\Delta V/V_0$'s at transition 023 and 113
[c] Transition at 9,500. $\Delta V/V_0$'s at transition 030 and 043

TABLE VI

$\Delta V/V_0$ of Four Miscellaneous Substances

Pressure kg/cm²	$AgBrO_3$	Pb	In	S
10,000	027	0215	0240	083
20,000	050	0410	0442	131
30,000	071	0587	0619	163
40 000	088	0747	0781	188
50 000	104	0892	0932	208
60 000	117	1024	1072	225
70 000	129	1145	1202	240
80,000	138	1255	1324	253
90,000	147	1356	1439	264
100 000	154	1449	1549	274

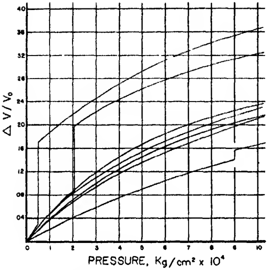

FIGURE 1 The volume decrements of the chlorides as a function of pressure. The order of the curves at 100,000 kg/cm², reading from top down, is Rb, K, Cs, NH_4, Tl, Na, and Ag

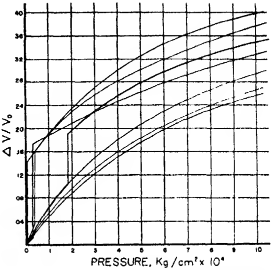

FIGURE 3 The volume decrements of the iodides as a function of pressure The order of the curves at 100,000 kg/cm², reading from top down, is Rb, NH_4, K, Ag, Cs, Na, and Tl

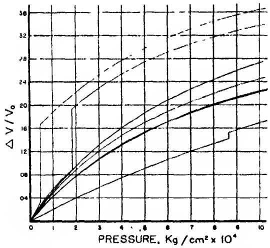

FIGURE 2 The volume decrements of the bromides as a function of pressure. The order of the curves at 100,000 kg/cm², reading from top down, is. Rb, K, Cs, NH_4, Tl, Na, and Ag.

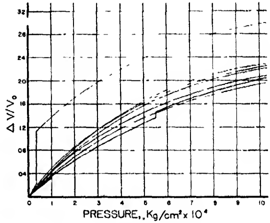

FIGURE 4. The volume decrements of the nitrates as a function of pressure The order of the curves at 100,000 kg/cm², reading from top down, is K, Cs, NH_4, Rb, Ag, Na, and Tl

important factor in determining compression at these high pressures. Disregarding the effect of polymorphic transition, and other things being equal, the compression increases on passing from chloride to bromide to iodide. The nitrates are about as compressible as the corresponding chlorides. With regard to the atom of the metal, the compression increases in the series sodium, potassium, rubidium, and caesium. The compounds of thallium in general show about the same compression as the corresponding sodium compounds, and the compounds of ammonium the same as those of potassium or rubidium. The compounds of silver are distinctly less compressible than those of any of the other metals just enumerated.

The falling off in compressibility with increasing pressure may be exhibited by comparing the volume decrement for the interval atmospheric to 50,000 with that for the interval 50,000 to 100,000 These values are listed in Table VII,

TABLE VII

COMPARISON OF VOLUME DECREMENTS AT LOW AND HIGH PRESSURES

Substance	$\Delta V/V_0$ 0–50,000	$\Delta V/V_0$ 50,000–100,000	Ratio
NaCl	135	075	1 80
CsCl	166	067	2 48
TlCl	144	009	2 08
NH_4Cl	154	073	2 11
NaBr	153	069	2 22
CsBr	186	086	2 16
TlBr	152	071	2 13
NH_4Br	170	074	2 29
NaI	184	082	2 24
CsI	208	086	2 42
TlI	177	079	2 24
$RbNO_3$	157	062	2 53
$CsNO_3$	165	061	2 71
$TlNO_3$	137	057	2 41
NH_4NO_3	162	061	2 66
$AgBrO_3$	104	050	2 08
Pb	089	056	1 60
In	093	062	1 52
S	.208	066	3 14

and are plotted in Figure 5 Figure 5 clearly shows the well known fact that in general the greater the absolute compressibility of a substance the more rapid its relative decrease of compressibility with increasing pressure It would, in fact, be surprising if something like this were not approximately the case, this being a geometrical consequence of the fact that an upper limit to the volume decrement is unity, negative volumes being meaningless. Figure 5 also brings out another general tendency, namely that other things being equal the substance with the more complicated atomic structure experiences the greatest relative decrease of compressibility with increasing pressure. This again would be expected on rather general grounds. The more complicated structure may be expected to have more internal vacancies or more "slack" to be taken out by the initial application of pressure In this respect the solid with complicated structure approaches more closely to a liquid, in which there is a large amount of internal slack and a rapid initial decrease of compressibility with increasing pressure.

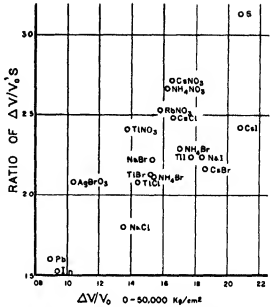

FIGURE 5 The ratio of the volume decrement 0 to 50,000 kg/cm² to the decrement 50,000 to 100,000 kg/cm² plotted against the volume decrement 0 to 50,000 kg/cm²

Only three examples of new polymorphic forms were found· $NaNO_3$, AgCl, and AgBr. It is perhaps surprising that not more were found, although in explanation it is to be commented that already at low pressures most of these substances must have already acquired about their maximum simplicity and symmetry of structure It is probable that the transitions of AgCl and AgBr are from the face centered lattice, which is the stable form at atmospheric pressure, to the body centered lattice, in analogy with the transitions of the potassium and rubidium halides It is of some interest that no transition was found for the sodium halides. A formal extrapolation of the results already found for the halides of rubidium and potassium might lead to the expectation of transitions of the sodium salts in the

new range. However, a careful calculation of the probable energy relations by Dr. Jacobs[6] has indicated that the probability of the transition fades out of the picture somewhere between potassium and sodium, and these experimental results support his conclusion.

There does not seem to be any simple method of guessing what the type of transition is for $NaNO_3$, the nitrates exhibiting a number of possibilities in the way of transition

On the basis of previous measurements[7] it might have been expected that transitions would have been found for rubidium, caesium, and silver nitrates. However, if the previous work is consulted it will be found that the transition of $CsNO_3$, which occurs in the neighborhood of 30,000, was getting so sluggish that it could not be picked up even with the former apparatus at temperatures below 125°. $RbNO_3$ similarly, which according to the former measurements has a transition at room temperature in the neighborhood of 17,000 kg/cm², is nevertheless so sluggish at this temperature that the band of indifference was 14,000 kg/cm² wide. It is therefore probable that the transitions of both $CsNO_3$ and $RbNO_3$ were totally suppressed in this work, and that the volume decrements listed here apply to the ordinary modifications, compressed far into their regions of thermodynamic instability. $AgNO_3$, on the other hand, according to previous work has a couple of transitions between 30,000 and 45,000 which might have been picked up. It is to be remarked, however, that the first of these transitions, from II to III, is sluggish, and may have been suppressed, the much greater speed and the much smaller quantity of substance in these experiments both being factors favoring suppression of the transition. It is true that the second transition found before, from III to IV, was not sluggish at room temperature, but if the transition from II to III had not previously occurred we would be concerned at high pressures with the transition II to IV, instead of III to IV, and there is no basis for judging whether the former transition would be sluggish or not The probability is, therefore, that all transitions were suppressed, and that the volume decrements of Table V are the decrements for phase II. Taken altogether, these results give increased probability to the correctness of Tammann's thesis, for which there was already much favorable evidence, that the probability of transition to the thermodynamically stable modification passes through a maximum and then decreases as pressure increases along an isotherm away from the point of reversible transition

It is a pleasure to acknowledge the skillful assistance of my mechanic Mr. Charles E. Chase.

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THE COMPRESSION OF SIXTY-ONE SOLID SUBSTANCES TO 25,000 kg/cm², DETERMINED BY A NEW RAPID METHOD

By P. W. Bridgman

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Contents

Introduction

In the following, a new apparatus is described by which the cubic compression of solid substances may be rapidly determined in the pressure range from atmospheric to 25,000 kg/cm² at room temperature, and the results obtained with it are presented for 6 elements, 26 salts, 15 organic solids, and 14 artificial and natural rubbers. The apparatus operates on about 0.1 cm³ of material, requires two hours or less for the complete run, including assembly, and disassembly ready for the next run, with 30 readings uniformly spaced over the pressure range. The individual points lie smoothly on a curve within 1 part in 2000 of the initial volume or better, depending on the nature of the material, with correspondingly greater accuracy in the mean curve

Apparatus and Method

The method is a development of the method previously used[1] for the determination of compressions and polymorphic transitions to 50,000 kg/cm². By this method, the material, enclosed in a sheath of a soft metal, usually indium, in order to ensure that the stress should be approximately hydrostatic, was placed in a steel container with an external conical surface fitting a steel sleeve, so designed that when the internal pressure increased the external pressure simultaneously increased, thus resisting the tendency to fracture. The volume compression was determined from the motion of the piston with which pressure was generated. The reduction of the measured piston displacement to volume decrement involved a number of corrections, which were somewhat in doubt because of friction and hysteresis. The pressure range was so high that the containers were subject to slow creep in dimensions, which always eventually resulted in fracture after anywhere from 10 to 100 applications of pressure.

The new and modified method in the first place restricts the pressure to one half the former range, with the object of avoiding creep and fracture and permitting the indefinite use of the apparatus. This appears to have been successful, and to date some 200 applications of 25,000 have been made with no fracture of any part of the apparatus and no measurable change of any dimension. The corrections, furthermore, are much simplified and minimized by so designing the apparatus that the change of cross sectional area of the container under internal pressure is small, leaving as the one most important outstanding correction one for the longitudinal compression of the carboloy pistons.

The apparatus is shown in detail in Figure 1. It is mounted on the same "tandem" hydraulic press that was previously used in the measurements to 50,000. This press comprises in the first place a 6-inch plunger, by which the pressure vessel is pushed as a whole into its conical sleeve so as to generate the external pressure resisting fracture. Riding on the 6-inch piston is a 3.5 inch piston by which pressure is exerted on the inside of the high pressure chamber. The core of the high pressure vessel itself is made of car-

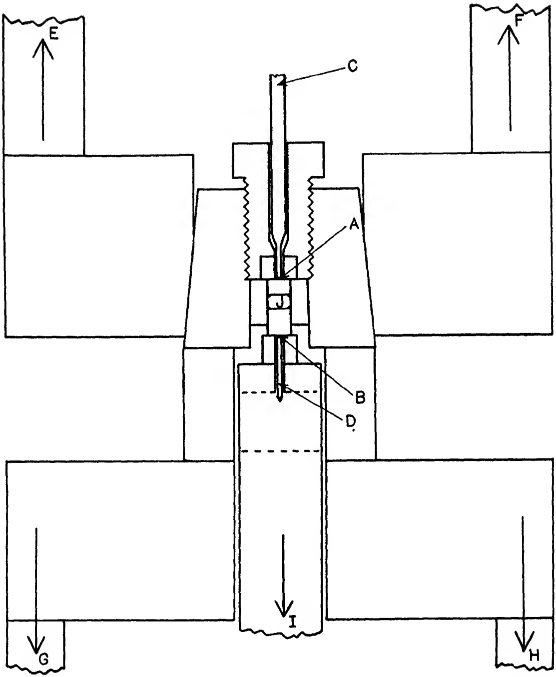

FIGURE 1 General assembly of compressibility apparatus. The charge whose compression is to be measured is shown at J The relative motion between the points A and B is taken off by means of the feeler rods C and D and a yoke and 1/10,000 gauge (not shown) The compression member I is actuated by the ram of the 3 5 inch press (not shown), and the conical vessel is pushed into its supporting collar by means of G and H actuated by the ram of the 6 inch press (not shown). The members E and F transmit the total thrust to the top platten of the tandem press (not shown).

boloy, grade no. 905, 0.47 inches long and 0.63 inches outside and 0.25 inches inside diameter, ground with a taper of 0.010 inches on its total length, and forced into the surrounding conical steel block to such an extent as to expand the inside of the steel block by 0.004 inch. In operation, the two pistons of the tandem press are both directly connected to the single source of hydraulic pressure, instead of being connected through a multiplying mechanism by which the pressure on the two pistons was previously maintained at a fixed ratio different from unity. In this way operation was simplified and error from friction in the multiplier avoided. The dimensions and angle of the steel block into which the carboloy core was forced were so chosen that the pressure on the outside of the carboloy was automatically maintained at about one quarter of the internal pressure. Under these conditions the internal expansion of the carboloy container keeps pace with the small lateral expansion of the carboloy piston so that the crack around the piston remains of constant size, and the tendency to leak, or the friction with the piston, does not increase It is to be remarked that apart from the other improvements in design, merely by making the core of carboloy the distortions were cut down to one-third of what they would have been with steel, because of the higher elastic constants of carboloy.

The charge, whose volume compression is to be measured, occupies the central part of the carboloy core, and is approximately 0 125 inches long and 0.250 inches in diameter. These dimensions are a compromise. The longer the charge, the greater the change in length for a given change of pressure, that is, the greater the sensitivity, but on the other hand, the greater the length, the greater the friction and the greater the error from difference between displacements with increasing and decreasing pressure. Theoretically, the ratio of the frictional force to the total compressing force may be made vanishingly small by indefinitely reducing the ratio of the surface on which the friction acts to the area on which the total compressing force acts, that is, by making the charge in the form of an indefinitely thin disc. But in this case the displacements which measure the volume compression also become vanishingly small. The dimensions just mentioned were chosen after some trial as giving a reasonable compromise.

The charge is compressed between two cylindrical carboloy blocks, the upper block in Figure 1 being held rigidly in place against a carboloy anvil inserted into the steel retaining screw, and the other block constituting the compressing piston. The relative displacement of the ends of these two blocks was measured by steel feeler rods reaching in through axial holes in the supporting carboloy anvil blocks as shown, and connected with an Ames 0.0001 inch jeweled gauge. The gauge had been specially selected by the manufacturers from a large number because of its negligibly small calibration errors. The relative displacement, measured in this way, is, except for the distortion of the blocks, the change of length of the charge, and from this, if the change of cross section of the charge is known, the volume decrement of the charge may be at once obtained. The distortion of the blocks consists primarily of a shortening, but superposed on this the faces in contact with the charge may not remain flat. With the dimensions chosen the effect of any warping of the plane ends of the blocks appears to be negligibly small, but the warping becomes relatively more important as the thickness of the charge is made smaller, and eventually would impose a limit, entirely apart from the effect of the decrease of the absolute magnitude of the measured displacement as the disc becomes thinner.

With the actual dimensions of the charge, 0.25 inch diameter and 0.125 inch long, the friction on the walls of the carboloy container generated by the longitudinal motion connected with the compression would have been excessive for most solid substances, so that it was necessary to surround the charge with a sheath of indium, as in previous work. The indium is so soft that it will support only an approximately hydrostatic pressure, thus producing the proper stress system on the charge and at the same time eliminating most of the friction on the walls. The indium, in weighed amount, usually in the neighborhood of 0.140 gm., was formed into a cup shaped sheath in place in the carboloy container with a suitably shaped forming tool, the thick bottom of the cup being in contact with the moving carboloy piston, and the thin edge of the cup being in contact with the stationary carboloy block. (Figure 2.) The solid to be measured was, if originally in the form of powder, formed into a conical slug by compression in a split mold, or, if it was coherent enough, was turned in the lathe from the massive block to such dimensions as to fit the inside of the indium cup. The indium was prevented from leaking past the carboloy pistons

by thin conical steel rings as indicated in the figure. These rings were made initially about 0.001 inch too large in diameter, but because of their thinness they could be seated in position with the exercise of only a moderate force They were effective in preventing any detectible leak. The quantity of steel in the sealing rings was controlled by weighing, the weight being about 0.015 gm each. A slight correction was applied for the compression of the rings.

Pressure was applied to the two pistons of the tandem press through the medium of ordinary

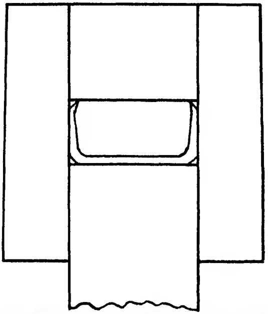

FIGURE 2 Detail of compression sample, showing the sample in the cup shaped indium sheath with the conical closure rings.

machine oil and the conventional hand pump The feeding pipe passed through a dead weight free piston gauge in series between pump and press. Freedom of flow through the connecting pipe between free piston gauge and press was lowered by plugging the pipe with a wire of diameter only slightly less than that of the pipe. In this way any pulses of pressure originating in the pumping or changing of weights on the gauge were avoided. This was necessary because pressure must increase or decrease monotonically in order to regularize what small friction effects there are and to justify eliminating them by taking the average of readings with increasing and decreasing pressure.

After setting up the apparatus, a preliminary application of the maximum pressure, about 26,500 kg/cm², was made in order to consolidate the contents. The initial zero may, depending on the degree of success in getting rid of all voids in the initial filling, be displaced by a considerable amount by this first application, but the piston reading at the first maximum of pressure seldom if ever differed by more than 0.0001 inch from the reading on the second maximum, showing the effectiveness of the preliminary application of pressure in removing all voids and bringing to a steady state. After the seasoning application, pressure was increased in steps of approximately 2,000 kg/cm² by the addition of weights to the piston of the dead weight gauge, and the corresponding readings made on the Ames gauge. Within the limits of comfortable operation of the apparatus, there were in general no time effects, but after every increase of pressure there was no creep in piston displacement, at least after the lapse of the 20 or 30 seconds after the piston gauge had reached equilibrium which was necessary before a reading could be made. Thermal effects are of course to be expected after every increase of pressure; the rapid attainment of equilibrium here is a consequence of the small size of the apparatus and its good thermal conductivity. The only point at which there was perceptible creep was at dead zero, where the elastic recovery imparted by the remnants of shape of the charge might result in the gradual development of voids. The dead zero reading was not used in the calculations, the first point being put at about 250 kg/cm². The actual process of making the run, increasing and decreasing pressure in steps of 2,000 kg/cm² and recording the readings required something of the order of 20 minutes. The rest of the operations of assembly, disassembly, plotting the points, etc. could be done without undue haste, if there were no unusual hitches, so as to make the total time of a run about one and one half hours.

It was intended to make the method differential like its predecessor. At first, measurements on a given substance were compared with blank runs in which the substance was replaced with an equivalent amount of gold, and the compression computed by difference, assuming the compression of gold known. The blank runs showed such a high degree of uniformity, however, that they were eventually discarded, their final function being merely to give the compressive distortion of the carboloy pistons. It turned out that the correction for the change of cross section

of the carboloy core was negligible, so that the final result could be obtained directly from the measured displacement, making one subtractive correction for the shortening of the pistons, another for the compression of the indium sheath, which was known in terms of the weight and the previous measurements of the compression of indium, and a very small correction for the compression of the steel sealing rings which was so nearly constant that it could be incorporated into the correction for the shortening of the pistons. The ratio of the corrected displacement to the initial effective length of the charge then gives at once the fractional change of volume, the relative change of cross section, as just mentioned, being negligible.

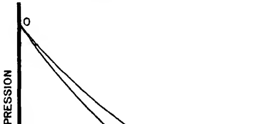

FIGURE 3 Typical compression curve.

The method as just described was arrived at only after a good many exploratory attempts to develop a method for the rapid measurement of the compressibility of solids to high pressures which should exploit the great ease with which rapid measurements of small displacements can be made with the jeweled Ames 0.0001 inch gauge, and the possibility of getting very high stresses in small regions of carboloy apparatus suitably supported by the surrounding parts. It is possible to reach pressures of more than 100,000 kg/cm^2 in carboloy apparatus similar to my shearing apparatus, and to measure the displacements of the pistons in compressing a very thin disc of material. Or, by making the disc somewhat thicker and compressing into a shallow cavity excavated in the face of a carboloy block, greater sensitiveness can be attained, but not such high pressures. None of the many other schemes tried, however, was encouraging from the point of view of accuracy and reproducibility, the distortions in the carboloy corresponding to dishing of the flat face of the piston in the apparatus above being too large a fraction of the total effect.

In Figure 3 is shown a typical curve of displacement versus pressure. The branch with increasing pressure, from O to A, is typically perfectly smooth, but the branch with decreasing pressure consists of three more or less distinct portions. The last part of the return excursion, from C to O, is smooth, and the difference of displacement compared with the ascending branch is approximately proportional to the pressure. The obvious interpretation of this portion is that the difference between the two branches is due to friction, which would be expected to be proportional to pressure, and that the proper mean to take is the arithmetic mean of the displacements with increasing and decreasing pressure. Before reaching C on releasing pressure the readings run through a stretch from B to C in which the difference between readings with increasing and decreasing pressure is approximately constant The first portion of the return path, from A to B, is merely a connecting link, without special significance, in which the full reverse motion of all parts of the charge gets progressively established. The interpretation of the constant difference between ascending and descending branches between B and C is suggested by my experiments on shearing under pressure.[2] Here it was found that when one solid is forced to slide over another under continually increasing normal pressure, at first the force resisting motion is an ordinary frictional force, arising from surface slip, and is proportional to the normal pressure, but when the normal pressure reaches such a value that the frictional force becomes equal to the stress required to produce internal plastic flow, surface slip ceases, and further relative motion is accomplished by internal plastic flow, the force being to a first approximation, and for not too wide pressure intervals, independent of pressure. This phenomenon was taken to be the interpretation of the constant difference between the two branches from B to C, and consequently the corrected mean curve between B and C is to be taken as half way between the ascending and descending curves, or, in this case, the curve for increasing pressure corrected by a constant additive displacement. Obviously the corrected curve between the pressure at B and the maximum at A

cannot be the mean of the displacements with increasing and decreasing pressure. If the above interpretation is correct, then the corrected curve between B and A is the curve for increasing pressure corrected by the same constant additive term as was used between A and B, neglecting the change with pressure of internal plastic flow stress, which previous work indicates is justified for this range of pressure. The data to be given in the following were obtained by correcting the measurements in this way.

The magnitude of the difference between ascending and descending curves is a strong function of the character of the material being compressed. It is least for soft metals. For indium the maximum difference in displacement between ascending and descending branches was only 0 0001 inch, which is of the order of one per cent of the maximum displacement for this metal. Probably only a small part of this difference arises from internal friction in the indium, but rather arises from friction in other parts of the apparatus. Friction would be expected at the two pistons of the tandem press, and on the outside of the conical block of steel. The pistons of the press were specially treated to reduce friction to a minimum by making the packing thin, the conical steel block was lubricated in the conventional way with 0 002 inch lead foil smeared on both sides with a mixture of graphite, glycerine, and water. An upper limit to the friction from all sources except internal friction in the charge itself would seem from these experiments with indium to be 0 5 per cent. From a minimum difference of 0.0001 inch between ascending and descending branches for indium, the difference might rise to 0 001 inch, ten times as much. Ten times as much does not mean, however, ten times as great proportional error, because the absolute values of displacement were also larger for these substances. It was very seldom that the difference between ascending and descending branches reached as much as 5 per cent of the maximum displacement, or a discrepancy of 2.5 per cent between the mean and either ascending or descending branch. Of course the accuracy of the mean itself should be much higher than this. Even so, it perhaps requires a word of comment as to why there should be as much discrepancy as this. If the indium sheath functions as intended and maintains a hydrostatic pressure on the charge inside it, one might perhaps at first expect no such effect at all, since hydrostatic compression is frictionless and without hysteresis. This applies, however, only to homogeneous material, isotropic or not. The material of these experiments was in most cases highly non-homogeneous, being compressed from powdered or granular material. If the material is non-cubic in its crystal structure, the linear compressibility is in general different in different directions, and the grains change shape under an external hydrostatic pressure. Therefore in a haphazard aggregate of grains of non-cubic material an external uniform hydrostatic pressure produces in general relative motion, with plastic flow and slip of one grain on another and hysteresis. In support of this, the difference between ascending and descending branches was comparatively small for cubic materials, even if they might be of comparatively high mechanical strength For example, the difference between different branches for NaCl was only about one-third as much as for naphthalene, although to ordinary mechanical stresses the latter is much more deformable than NaCl.

The preliminary work in developing the apparatus and technique of measurement was done with NaCl-clear single crystal stock The presumptive accuracy of the method can be estimated from a comparison of the results obtained in this apparatus with previous results determined in the pressure range up to 50,000 kg/cm², as shown in Table I

TABLE I

COMPRESSION OF NaCl

Pressure kg/cm²	$\Delta V/V_0$ Present Measurements	Previous Measurements to 50,000
5,000	0189	0192
10,000	0362	0365
15,000	0520	0523
20,000	0664	0664
25,000	0795	0798

DETAILED RESULTS

1. *Elements*. Occasion was taken to fill in certain gaps in the compressions of the elements which for one reason or another had not been previously measured to pressures high enough to give an indication of the change of compressibility with pressure. The new values are collected in Table II.

Thallium. This has not been previously measured in the range below 25,000. Thallium crystallizes in the hexagonal system so that a complete description of the behavior under pressure demands a measurement of the linear

TABLE II

COMPRESSION OF ELEMENTS

Pressure kg/cm²	Thallium	Arsenic	Cadmium	$\Delta V/V_0$ Indium	Lead			Ceylon Graphite
					These measurements	From linear compression	Powder	
5,000	0130	0119	0100	0127	0110	[0112]	0170	0138
10,000	0251	0221	0194	0241	0215	[0219]	0323	0260
15,000	0367	0309	0283	0347	0315	[0321]	0460	0366
20,000	0476	0385	0368	0445	0411	[0419]	0583	0458
25,000	0577	0447	0449	0537	0504	[0513]	0718	0535

compression parallel and perpendicular to the hexagonal axis of the single crystal. I had hoped when making the low pressure measurements to be able to operate with the single crystal, but have not yet successfully prepared single crystals of this metal, the difficulty with the method which I had previously used for the other low melting metals being that thallium attacks the glass container. The volume compression could now, however, be so easily obtained with the new apparatus that it seemed worth while, even if the results would not be complete. The material was some highly purified metal which I had inherited from Professor T. W Richards, used by him in his measurements of compression in the range up to 500 kg/cm² Thallium is so soft that it could be compressed directly into the carboloy container without the necessity for a sheath of indium. The difference of displacements with increasing and decreasing pressure was at most only 2 per cent of the maximum displacement. The compressibility at atmospheric pressure, extrapolated from these measurements, was found to be 2.7×10^{-7}, against the value of Richards and White[3] of 2 78 in the range up to 500 The agreement is within the sensitiveness of the readings, and again gives presumptive evidence of the reliability of this new method.

Measurements have already been presented[4] for the compression of thallium in the 100,000 apparatus, the range of those measurements being from 25,000 to 100,000. At that time, the fiducial change of volume at 25,000, necessary for the calculations, had not been determined, and it was arbitrarily assumed that the volume decrement was the mean between that of lead and indium, or 0.052. The fiducial volume decrement at 25,000 is now found by direct measurement to be 0.0577. This will permit a re-evaluation of the compressions to 100,000, which will be given in a following paper.

Arsenic. This, like thallium, does not crystallize in the cubic system; it is furthermore known to be highly non-isotropic. The material was highly purified single crystal stock prepared by Dr W. E. Danforth a number of years ago, the same material as that used in a detailed study of the many anomalies of linear compressibility and electrical resistance of this highly abnormal metal.[5] The sample used in the present measurements was composed of a number of single crystal grains compressed together in haphazard orientation The regular indium sheath was used Considerable difference between readings with increasing and decreasing pressure was to be expected because of the mechanical hardness and high non-isotropy The maximum difference between displacements with rising and falling pressure was 10 per cent of the maximum displacement. The average should be fairly good, because rising and falling curves were smooth, with no trace of the anomolies previously found in the linear compression, which indeed was not to be expected because those anomolies were on too small a scale. The initial compressibility at atmospheric pressure, extrapolated from the present measurements, is $2\ 5 \times 10^{-6}$. This is to be compared with the value 3.2×10^{-6} deduced from my previous measurements of linear compression in different directions, and the value of Richards[6] of $4\ 4 \times 10^{-6}$ in the pressure range below 500 kg/cm². The explanation of the latter high value is doubtless the formation of voids because of unequal compressibility in different directions.

Cadmium. This material also does not crystallize in the cubic system, so that a complete description of the phenomena of compression demands a measurement of the linear compression of the single crystal in different directions The measurement of linear compression, however, encounters an unusual complication, because in the single crystal form there are polymorphic transitions at comparatively low pressures,[7] and on passing through them the single crystal form is lost, so that measurements of

linear compression cannot be carried above the transition pressure. The average volume compression as measured here presents, therefore, only a partial picture, but seemed to be worth while in the absence of other information

The material was spectroscopically pure, for which I am indebted to Dr H. M. Cyr of the New Jersey Zinc Co. It was mechanically soft enough so that it could be used without the indium sheath without undue friction The initial compressibility at atmospheric pressure, extrapolated from the volume decrements given in the table, is $2\ 06 \times 10^{-6}$, which is to be compared with 2.21×10^{-6} obtained indirectly from the measured elastic constants of the single crystal.[7] The anomalies previously found in the linear compression would not be expected to be detectible with the present method.

Indium. The reason for making new measurements on this metal was the continued use of its compression in correcting the other measurements. The material was probably not of specially high purity, it is part of the same stock that has been used in all my other work. The new measurements should be better than any others hitherto made; it has already been mentioned that friction and hysteresis were reduced to a very low value. The deviation of the new values from those last published[8] for the range up to 100,000 kg/cm² is not great; at 10,000, 0 241 now against 0.023 previous; and at 20,000, 0.0445 now against 0 045 previous. The new values to 25,000 have afforded the basis for improved measurements to 100,000 which have been communicated in the immediately preceding paper.

Lead. The only previously published values to high pressures[9] reach to 45,000; these measurements were rough, being among the earliest obtained by this general method, before the later refinements had been worked out.

The material was 99,9999 per cent purity lead, which I owe to the kindness of Dr. Phillips, to whom it had been sent by the Federated Metals Corporation, 120 Broadway, New York City. This material is particularly well adapted to the new method because of its mechanical softness It was used without the indium sheath; the maximum difference between ascending and descending readings was 0 0002 inch. The values now found are to be compared with the previous values in the range to 45,000 as follows: at 10,000, 0 0215 now against 0.023 previous; and at 25,000 0 0504 now against 0 050 previous.

In addition to these values, measurements as yet unpublished were made in 1939 by the method of linear compression with sliding potentiometer wire to 30,000 kg/cm², using in the calculations recently redetermined values for the linear compressibility of iron. They should have the highest accuracy that I have yet reached. A more detailed account will be published of this work when I have had opportunity to add more materials, which at present embrace only lead, aluminum, copper, and pure iron from two sources In the meantime, the results by this method are given in Table II for comparison, enclosed in brackets. The absolute values of the presumably more accurate method are consistently higher than by the method of this paper. It is significant, however, that the rate of decrease of compressibility with pressure by the two methods is the same to the limit of significant figures It is to be emphasized that these two methods are quite independent of each other.

On the basis of these new measurements the compression of lead has recently been measured up to 100,000; the results are given in the preceding paper.

In connection with other measurements occasion arose to measure the compression of finely powdered lead. It might perhaps be expected, because of the mechanical softness of lead, that virtually perfect compacting would be achieved at these high pressures, and that the compression would be the same as that of the massive metal. This proved to be by no means the case, however. After the first application of 25,000 there was no further perceptible change of volume on the second and third applications. In spite of this, the compression, as shown in Table II, was consistently higher, initially by a factor of 1.54 and at 25,000 by a factor of 1.45 The density at atmospheric pressure of the powder after exposure to 25,000 was 10.74, against 11 34 for the massive pure metal. However, only a small part of the difference between these two densities probably represents voids in the compressed powder. The reason for this statement follows. The compression measurements on the powder were continued in the other apparatus to 100,000. After exposure to 100,000 the density was 10.86. The compression of the powder in the range between 25,000 and 100,000 was sensibly the same as that of the massive metal. It is probable therefore that the pressure of 100,000 was enough to sensibly squeeze out all the voids. The difference between the densities 10.86 and 11.34 is probably to be laid to the account of impurities having

considerable mechanical strength, occluded on the surface of the grains of powder, perhaps oxides. In the present experiments only the difference between 10.74 and 10.86 is to be laid to voids. No simple method of effecting a reconciliation between all the figures just given presents itself, but at any rate we have here a dramatic instance of the very great difficulty of getting good values for the compression of compressed powders even under apparently the most favorable conditions.

Graphite. The only measurements of the compressibility of graphite in the literature were made by Richards and collaborators[11] on graphite from "both artificial and natural sources."

Measurements were now made on three different grades of material. The first of these was massive graphite prepared at Niagara Falls by the Norton Co., highly purified, and subjected before measurement to a further exposure to approximately 3000° C at atmospheric pressure. This material was very porous, the density at atmospheric pressure after a preliminary excursion to 25,000 being only 1.80. Measurements were made on the massive slug, without the indium sheath. Under 25,000 kg/cm² it experienced a volume change of 11.5 per cent, half of this occurring in the first 5,000 kg/cm². In view of the high porosity it will not pay to give the results in greater detail, The results are chiefly valuable in emphasizing the extraordinary degree to which porosity persists after exposure to high pressures, even in materials comparatively weak.

The second material was Acheson flake graphite, compressed to a slug completely filling the apparatus without the indium sheath. After exposure to 25,000 the density was 2 13, the volume change under 25,000 was 7 5 per cent The behavior was roughly like that of the Norton massive graphite, with elimination of the very compressible part of the curve in the first few thousand kilograms. The friction and hysteresis of both the massive and the Acheson graphite were not excessive, being about that of the average material of these experiments.

The third material was natural single crystal stock from Ceylon, in the form of flat flakes a few square centimeters in surface area and 0.010 to 0.020 inch thick. Discs of 0.25 inch diameter were cut from the flakes with a tubular cutter, and the discs were piled flat into the pressure chamber, without the indium sheath. The density at atmospheric pressure after precompression to 25,000 was 2.23. Results with this material were very satisfactory. Friction and hysteresis were minimal, being no greater than for indium itself. Neither was there any region of abnormally high compressibility at the low pressures, but the internal evidence was that the material is sensibly compact. The volume decrement under 25,000 was 5.35 per cent; the results are given in Table II. The initial compressibility, extrapolated to atmospheric pressure, is $2\ 92 \times 10^{-6}$, to be compared with "not greater than 2.9×10^{-6}" by Richards and collaborators.[11] The compressibility of graphite appears to be about fifteen times as great as that of diamond, not a surprising result in view of the great difference of densities.

2. *Inorganic Salts.*

A. *Univalent Nitrates.* Results have been presented in the preceding paper for the compression of these substances in the complete pressure range up to 100,000 kg/cm². The measurements with the present apparatus up to 25,000 were made primarily to provide the necessary fiducial volume decrement needed before the measurements to 100,000 could be reduced, and also to provide the initial part of the compression curve, the compression of these substances not having been previously measured in any extensive pressure range. In general the materials were the same as have been used in previous investigations of polymorphic transitions under pressure;[12] reference is made to the previous paper for details The results are given in Table III, to one more significant figure than in the preceding work to 100,000. The values given here are those obtained immediately with the present apparatus, with no attempt to reconcile the measurements in the lower range with those to be reported presently in the higher range.

Apparently the only compressibilities in the literature by other observers for any of the nitrates are by Madelung and Fuchs[13] for $NaNO_3$ and $AgNO_3$. For the compressibility of these in the pressure range 200 to 500 kg/cm² they found 3 75 and 3.60×10^{-6} respectively against the values 3 8 and 3.5 given by extrapolation of the values in Table III. There are also measurements of my own[14] on the linear compression in different directions of the single crystal up to 12,000 kg/cm². The cubic compressibility may be calculated from the linear compression. The initial compressibility is 3.85×10^{-6} against the value 3.8 above. The volume decrement at 10,000 kg/cm² obtained by calculation from the

TABLE III

COMPRESSION OF NITRATES

Pressure kg/cm²	$\Delta V/V_0$ NaNO$_3$	KNO$_3$	RbNO$_3$	CsNO$_3$	AgNO$_3$	TlNO$_3$	NH$_4$NO$_3$
2,000	0074	0135	0093	0103	0068	0082	0117
3,650		0229 1129					
5,000	0179	1185	0225	0247	0165	0109	0274
9,500					0300 0427		
10,000	0339	1378	0427	0460	0443	0377	0499
15,000	0482	1542	0608	0645	0593	0534	0688
20,000	0611	1682	0768	0805	0725	0671	0845
25,000	0728	1801	0913	0943	0842	0790	0979

measurements on the single crystal is 0.0346 against 0 0339 of the present measurements.

It is of interest to consider the relative compressibility of polymorphic forms at a transition. $AgNO_3$ experiences a transition at 9,500; the data in the table indicate that the low pressure form has a compressibility at the transition point of approximately $2\ 85 \times 10^{-6}$, and the high pressure form at the same point has 3.25×10^{-6}. That is, the compressibility increases on passing through the transition with decrease of volume, a result which appears paradoxical, but which nevertheless is the behavior at the majority of transitions. KNO_3, the only other nitrate with a transition in the present pressure range, shows the opposite behavior The low pressure form of this is highly compressible, and the compressibility drops rapidly with increasing pressure, from approximately $7\ 4 \times 10^{-6}$ at atmospheric pressure to $5\ 2 \times 10^{-6}$ at the transition point at 3,600 kg/cm² The compressibility of the high pressure modification at this point is $4\ 2 \times 10^{-6}$, a 20 per cent drop. Above 3,600 the compressibility drops at a slower rate than does that of the low pressure modification

B *Certain Halogenates and Perhalogenates.* Previously[14] a study has been made up to 50,000 kg/cm² of the polymorphic transitions of univalent compounds of the types R Hl O_3 and R Hl O_4, where Hl stands for one of the halogens chlorine, bromine or iodine. Measurements of the compressions of these same compounds are now given here In general, the materials were the same as used before, left from the previous work, and the previous paper may be consulted for such details as purity. Three of these substances, however, were new· $LiClO_4$, $NaClO_4$, and $KClO_4$. These had been specially purified by Professor K. Fajans, who was interested in their properties from another point of view, and who requested me to measure their compressions. He has discussed the results in another place.[15] The preparation of these three salts offers unusual difficulties, and Professor Fajans exercised unusual precautions to secure high purity and freedom from moisture. They were supplied to me in glass stoppered paraffine covered bottles The pressure apparatus was set up as rapidly as possible in order to avoid absorption of moisture from the air. The entire time from opening the bottle to complete enclosing in the pressure apparatus and preliminary application of pressure was about 5 minutes; during most of this time the material was partially covered, exposed to air only on edges and corners

Of these three perchlorates, $LiClO_4$ has a transition not known before in the average neighborhood of 16,400 kg/cm². The transition is very sticky, it does not start with increasing pressure until about 19,000, and runs slowly, probably being completed only just below the top pressure. On decreasing pressure the reverse transition does not start until reaching 13,000. The compression of the low pressure form should be satisfactory, but under the conditions the change of volume on passing through the transition and the compression of the high pressure phase can be expected to be only rough.

The results are given in Table IV. In general, the compression increases on passing from lithium to sodium to potassium to rubidium to caesium, although there is an exception in the relative position of rubidium and caesium in the perchlorates. Analogy, and also experience with the simple halogen compounds of the type NaCl, would lead to the expectation that compression should similarly increase on passing from chlorine to bromine to iodine. This effect, however, is much less marked in these compounds. It is recognizable in the series $NaClO_3$, $NaBrO_3$, $NaIO_3$, but in the perchlorates of sodium, potassium, and rubidium there is a falling off of compression on passing from the chlorine compounds to those of iodine which seems beyond any possi-

TABLE IV

COMPRESSION OF HALOGENATES

Pressure kg/cm²	$\Delta V/V_0$ $NaClO_3$	$KClO_3$	$CsClO_3$	$NaBrO_3$	$AgBrO_3$	$NaIO_3$	KIO_3	NH_4IO_3
2,000	0069	0104	0108	0071	0057	.0068	0068	0057
5,000	0165	0259	0257	0171	0138	0165	0161	0138
10,000	0307	1044[a]	0478	0320	0266	0312	.0298	0266
15,000	0431	1217	0666	0450	0384	0444	0417	0384
20,000	0542	1362	0827	0567	0490	0564	0522	0490
25,000	0644	1483	0967	.0673	0586	0675	0619	0586

[a] Transition at 7,500 with volume decrements 0388 and 0944

COMPRESSION OF PERHALOGENATES

Pressure kg/cm²	$\Delta V/V_0$ $LiClO_4$	$NaClO_4$	$KClO_4$	$RbClO_4$	$CsClO_4$	NH_4ClO_4	$NaIO_4$	KIO_4	$RbIO_4$	NH_4IO_4
2,000	0078	0079	0088	0102	0098	0125	0078	0079	0093	0081
5,000	0189	0191	0213	0245	0232	0288	0184	0190	0219	0195
10,000	0359	0364	0404	0460	0427	0519	0336	0355	0400	0368
15,000	0509	0519	0574	0647	0598	0716	0463	0497	0553	0524
20,000	0802[a]	0659	0724	0817	0750	0885	0569	0617	0685	0664
25,000	0928	0784	0854	0971	0890	1031	0658	0820	0809	0791

[a] Transition at 16,400, with volume decrements 0557 and 0717

ble experimental error. In searching for an explanation, the effect of crystal structure must obviously be taken into account, polymorphism being common, and there being several types of possible structure

Previous measurements[16] have been made on the linear compression of single crystals of $NaClO_3$ and $NaBrO_3$ in the range up to 12,000 kg/cm². The initial compressibilities calculated from these measurements are 4.9 and $4\ 3 \times 10^{-6}$ respectively, against 3 6 and 3.7 given by extrapolation of the values in Table IV. The discrepancy is much beyond the experimental error of the present method, and the explanation of it is not clear. However, it is probable that the previous measurements should be disregarded; these were made by a new method, which has been applied to only a few substances, and which has never been adequately checked. The method was especially devised to apply to substances which are acted on by kerosene, and employed smaller samples than usual, mounted in a complicated way under the surface of mercury.

3. *Organic Solids.*

A. *Definite Compounds* A few simple compounds were investigated, with a range of types of composition. They were taken from the regular stock of the Harvard Chemical Laboratory. In spite of the mechanical softness of organic solids in general under atmospheric conditions, the indium sheath was used in all the measurements. This proved to be necessary, the difference between the ascending and descending branches in general being of the same order of magnitude as for the inorganic compounds This is perhaps not too surprising, because it has already been found that under high pressures such organic compounds as rubber may acquire a high rigidity, greater even than that of mild steel under the same pressure.

The results are collected in Table V. Under the name of each substance is the density assumed in the calculations. This density was obtained from the measurement of the dimensions of the charge after release of pressure and removal from the apparatus. It is likely to be slightly and consistently in error on the small side, because of a slight swelling in volume on removal from the apparatus due to the elastic springing back of voids not crushed completely flat by the high pressure. The assumed density enters the calculation in such a way that, if at some future time better values are obtained for the density of the perfectly compacted material, the relative compressions given in the table may be corrected by multiplying by the ratio of the corrected density to the assumed density. This means that in general the volume compressions given in Table V are probably slightly too low.

Among these organic solid compounds the compression at 25,000 kg/cm²; ranges from 0 1959 for menthol to 0.0901 for dextrose, or by a factor of 2.2. The initial compressibilities of these two substances, extrapolated to atmospheric pressure, are in the ratio 3.5. This is consistent with the

TABLE V

COMPRESSION OF ORGANIC SOLIDS

Pressure kg/cm²	Levulose	Dextrose	Dextrin	Starch	Menthol	Naphthalene	Anthracene	Triphenyl Methane	Thymol	Succinic Acid	Anthroquinone	Benzophenone	Amino-Benzoic Acid		
						$\Delta V/V_0$									
	1 570	1 467	1 48	1 45	0 923	1 154	1 197	1 106	1 014	1 506	1 398	1 140	ortho-	meta-	para-
2,000	0100	0101	0203	0234	0342	0309	0240	0293	0235	0178	0215	0296	0168	0225	0235
5,000	0239	0239	0452	0486	0701	0630	0505	0598	0694	0405	0453	0605	0374	0425	0493
10,000	0445	0439	0764	0794	1114	1076	0842	0961	1094	0705	0743	0981	0644	0665	0813
15,000	0625	0611	1004	1023	1428	1281	1095	1230	1380	0940	0965	1255	0863	0848	1054
20,000	0783	0763	.1194	1213	1702	1493	1291	1437	1612	1130	1146	1473	1045	1004	1252
25,000	0923	0901	1353	1387	1959	1674	1460	1618	1829	1290	1307	1657	1203	1146	1428

general experience that a compressibility, initially high, tends to drop off more rapidly with increasing pressure.

There is a rough correlation between the compressions and the densities, the least dense compounds being in general more compressible; the correlation is better at high than at low pressures. The correlation is still closer if one plots the compressibility at the upper end of the pressure range. This is shown in Figure 4, in which are

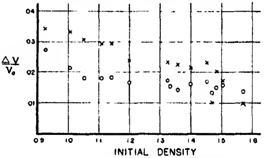

FIGURE 4. The compression of various organic solids as a function of the initial density. The crosses show the relative volume decrements between atmospheric pressure and 2,000 kg/cm², and the circles the relative decrements between 20,000 and 25,000

plotted as crosses the volume decrement from 0 to 2,000 kg/cm², and as circles the volume decrement between 20,000 and 25,000 kg/cm². The latter set of points lies more nearly on a single curve, and furthermore the curve which best represents the points runs with less change of height from low density to high density. The correlation with density is not materially changed if one plots the final compressibility against the final density instead of against the initial density. In any event, the final compressibility for the denser materials tends to level off to an approximately constant value of 3×10^{-6}. The substances for which there is the greatest failure of correlation between density and compressibility, both at high and at low pressures, are starch and dextrin, the former having abnormally high compressibility and the latter abnormally low.

The reversal of order of densities with pressure in the series of isomeric forms of amino-benzoic acid merits special mention. At atmospheric pressure the densities increase in the order para, ortho, meta, whereas at 25,000 the order is meta, para, ortho, involving a transfer of the meta compound from the head to the foot. The subject is worth further investigation.

It is natural to look for a correlation between the compression at high pressures and the chemical composition. This, however, did not prove especially fruitful It appears that there is a general tendency for compounds with a large proportion of carbon or of hydrogen in their composition to be relatively compressible, and with a large proportion of oxygen to be relatively incompressible, but further than this no obvious correlation appeared.

B. *Synthetic and Natural Rubbers.* The measurement of these was undertaken at first for the entirely practical purpose of finding some way of predicting which might be expected to function best for high pressure packing on the piston of the apparatus for 30,000 kg/cm². There is considerable difference in the behavior of different rubbers as packings; most rubbers crack at these high pressures, and in some the cracking is so extensive that leak is of frequent occurrence. The cracking probably arises from a combination of circumstances In the first place, the rubber becomes harder and brittle under pressure exactly as when plunged into liquid air, the phenomenon being essentially a raising of the freezing point with pressure. In the second place, the rubber thus embrittled must be deformed by the unilateral compressive stress arising from the unsupported area principle of the packing sufficiently to neutralize the effect of the uniform volume compression which it would receive under the action of the fluid pressure alone, so that it will again tightly fill the packing space; otherwise leak will occur. This deformation of the embrittled rubber is the probable origin of the cracking. One would expect that, other things being equal, it would be least in those rubbers with the smallest natural volume compressions, and this was the clue followed in the exploration. The distortion necessary to bring the rubber back to fill the packing hole is not small at these pressures Thus one typical synthetic shows a volume loss of 21 per cent at 25,000 kg/cm²; the corresponding decrease of linear dimensions is 7.6 per cent, which means that the embrittled solid must expand under the unilateral compressive stress by some 8.2 per cent in linear dimensions, preferably without cracking. No rubber has been found entirely free from cracking under these conditions, the best that can be hoped is to find one in which the cracks that do form are not so serious but that they can be sufficiently sealed by the lateral compression.

Ten different specimens of various synthetic rubbers were collected from dealers in the neighborhood of Boston Measurement disclosed an interesting feature, namely in some of them there was a rather sharp change in the direction of the curve of volume versus pressure, or discontinuity of the second kind, at pressures roughly of the order of 5,000 kg/cm² I had the privilege of discussing this result with Dr. E. Guth, and it seemed to him of sufficient interest to justify examination of specimens whose composition was more definitely known than of the commercial specimens He accordingly was kind enough to send me 6 representative rubbers of which the compositions are known; the results for four of these are included here and those for the other two will be published later

The compositions are as follows

	Hevea Gum	Hevea Tread
SS	100	100
Stand. Micronex	—	52
ZNO (Fast Curing)	3	3
Stearic Acid	4	4
Pine Tar	2	2
Antioxidant	1 5	1 5
S	2 7	2 7
Captax	0 9	0 9

	Butyl Gum	Butyl Tread
Butyl B	100	100
Zinc Oxide	5	5
Stearic Acid	3	3
Sulfur	1 5	1 5
Cabot no 9, Black	—	50
Treads	1	1
Captax	—	0 5

The retraction process and certain other physical properties of the Hevea rubber have been described in recent letters in the Physical Review.[17] Certain properties of the butyl rubber are to be published in a forthcoming number of the Journal of Applied Physics, and were presented at the Rochester meeting of the American Physical Society in the summer of 1944.

The material was cut to the full diameter of the carboloy container and used without the indium sheath. The specimens from Dr Guth were dimensioned with particular care, being ground to dimensions on one flat face and on the curved face.

In Table VI the compressions for 12 synthetic rubbers and 2 natural rubbers are given. The table also gives the densities at atmospheric pressure calculated from the measured dimensions of the charge at atmospheric pressure, be-

TABLE VI

COMPRESSION OF SYNTHETIC AND NATURAL RUBBERS

Pressure kg/cm²	Duprene	Koroseal no 89023	Neoprene no 832	Buna S no 8774	Ameripol D-7700	Hood 844A	Goodrich D-402	Goodrich D-420	Goodrich D-453	Goodrich D-453	Butyl Gum	Butyl Tread	Hevea Gum	Hevea Tread
	$\Delta V/V_0$													
	1 589	1 250	1 357	1 376	1 370	1 176	1 193	1 350	1 513	1 309	0 967	1 125	0 950	1 122
2,000	0302	0511	0460	0465	0367	0407	0422	0385	0329	0432	0519	0423	0535	0462
5,000	0615	0967	0956	0872	0715	0792	0837	0745	0636	0842	0945	0807	1017	0870
10,000	0898	1403	1294	1238	1052	1163	1194	1128	0938	1208	1303	1129	1422	1250
15,000	1198	1679	1567	1493	1304	1445	1454	1378	1162	1480	1543	1334	1697	1490
20,000	1301	1891	1793	1715	1507	1663	1670	1587	1347	1692	1744	1510	1929	1707
25,000	1462	2060	1990	1903	1686	1840	1847	1769	1513	1862	1920	1667	2116	1900
Pressure of Discontinuity	3,500		4 800	6,300	4,900		4 800				6 200			6,500
Amount of Discontinuity	2 0 $\times 10^{-4}$		5 3 $\times 10^{-4}$	3 4 $\times 10^{-4}$	1 5 $\times 10^{-4}$		3×10^{-4}				5×10^{-4}			2×10^{-4}
$\Delta V/V_0$ at Discontinuity	0516		0939	1012	0707		0851				1083			.1026
Ratio of Width of Hysteresis Loop to Maximum Displacement	083	.059	082	087	064	067	072	080	103	077	083	090	074	073

for it had been removed from the pressure apparatus. Thus the expansion on removing from the apparatus, which was a source of error in some of the other densities, was not present in these measurements for rubber, which should be substantially correct. It will be seen that, just as in the case of the solid organic compounds, there is a certain correlation between the compression and the density. This correlation is, however, not so close for the rubbers as for the compounds, as indeed might be expected in view of the fact that there is an artificial factor in the density of the rubbers in the varying degree of loading with carbon black.

The table gives data for the discontinuity of the second kind, that is, the discontinuity in slope, exhibited by 7 of the rubbers. There is listed the pressure of the discontinuity, the volume decrement at the pressure of discontinuity, and the amount of discontinuity in the derivative $\left(\frac{\partial v}{\partial p}\right)_\tau$; in all cases the discontinuity is in the direction of a smaller slope at the higher pressure. No great amount of precision can be claimed for the numerical values of these discontinuities, as is always the case in attempting to measure a discontinuity. In fact, from the point of view of logical rigor, not even the existence of a discontinuity in the mathematical sense can ever be established by physical measurements; it is merely that a discontinuity is the simplest way of reproducing the results to the natural order of accuracy. In any event, there can be no mistaking the striking qualitative difference between the curves for substances like neoprene and Hevea gum. An active imagination would be tempted to find other discontinuities in the curves than those given; only the apparently inescapable ones were listed. One particularly tempting example is afforded by Hood 844A, in which there seems to be rather definitely a discontinuity in $\left(\frac{\partial^2 v}{\partial p^2}\right)_\tau$ near 6,000 kg/cm^2. The physical significance of these discontinuities is probably merely that some rubbers pass more abruptly into the "frozen" condition than do others.

Table VI contains, in addition to the matters just discussed, the width of the hysteresis loop, that is, the ratio of the maximum difference between displacements with increasing and decreasing pressure to the maximum displacement. This varies by a factor of 1.75 fold, somewhat more than does the density or the compressibility. Several factors obviously enter into the width of the loop. There is in the first place the ordinary coefficient of friction of the rubber against the carboloy walls. In the second place there is the internal plastic flow stress within the body of the rubber. In the third place, there is lag, subcooling or superheating, between the ordinary state and the "frozen" state.

Returning to the problem which originally suggested the measurement of the rubbers, it is to be remarked that the single criterion of compression at high pressures did not prove an adequate characterization of the behavior as a high pressure packing. There are other features which are involved in the functioning as packing. Thus, the friction with the steel walls of the pressure vessel must not be too great, and the shearing strength against this frictional drag must be sufficient. Certain of the artificial rubbers which appeared promising from the point of view of volume compression had such a combination of high coefficient of friction and low mechanical strength that when used as packing a vortex ring of rubber was detached from the body of the packing at the periphery and rolled over and over against the steel walls as the plunger advanced. It still remains necessary to make actual trial to determine the suitability for high pressure packing As yet, exhaustive trial has not been made of the suitability of all the rubbers for high pressure packing, but to date Duprene seems the best for all round use. It happens that Duprene also has the smallest compression.

I am indebted to my mechanic Mr. Charles E. Chase for the skillful construction of the apparatus, and to the Carboloy Company for the carboloy used in this and the preceding paper

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LOWER PERMIAN INSECTS FROM OKLAHOMA. PART 1.

INTRODUCTION AND THE ORDERS MEGASECOPTERA, PROTODONATA, AND ODONATA

By Frank M. Carpenter

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Introduction

During the past two decades our knowledge of Permian insects has been greatly increased. This has mainly resulted from the collection and study of several thousand specimens from strata in Kansas, Russia and Australia. The rocks in Kansas, termed the Elmo limestone by Dunbar (1924), are geologically the oldest; they belong to the Wellington formation, which is well within the Lower Permian and not far from its base. The correlation of the Russian and Australian beds is not so certain, but they are probably correctly referred to the Upper Permian. The Elmo beds have accordingly been unique: they have provided us with almost the sole record of an early Permian insect fauna. It has been my hope for many years that another insect-bearing bed of equivalent age would be found, especially one deposited under environmental conditions different from those responsible for the Elmo limestone.

This hope has now been realized. In 1939 Dr. G. O. Raasch sent me about seventy well-preserved insects which he had collected in certain Wellington strata in Noble County, Oklahoma. A study of the specimens convinced me that further exploration of these rocks would add substantially to our knowledge of Permian insects, and I accordingly spent the following summer collecting in the region. In this undertaking I was fortunate in having the aid of Dr. Raasch, who made a careful stratigraphic study of the area, and was able to trace the insect-bearing rocks over an area of about 400 square miles In about ten weeks we collected more than five thousand well-preserved insects.

Dr. Raasch's detailed account of the Wellington formation in Oklahoma is being published elsewhere, but with his permission I include here a summary of his conclusions on the origin of the insect-bearing rocks and the environment of the biota. The Wellington formation as a whole covers a large area. It was deposited in a great water-filled basin, the Wellington Sea, occupying parts of Oklahoma, Kansas, Nebraska and Colorado. In Pennsylvanian time typically marine waters from the ocean to the south periodically invaded the basin and this inflow continued until early Wellington time. By mid-Wellington, typically marine conditions had ceased to exist in the basin and the climate of the region had become more arid. Although inflow of marine waters continued periodically, presumably through a restricted connection from the open sea to the southwest, the waters covering the basin were at all times of more than marine salinity. The conditions alternated between those of a great salt lake and of a vast, dessicating mud-pan. This alternation was especially pronounced at the time of deposition of the strata in Noble County which Raasch has termed the Midco member of the Wellington formation. This member is about 255 feet thick and is composed mainly of alternating lumpy, clay-shales and fissile, flaky shales. Included in this series is the insect bed Varying from about six inches to four and a half feet in thickness, it consists in reality of several layers of fine-grained, compact, argillaceous dolomitic limestone, separated by fissile shale. Three of the limestone layers contain insects, and for convenience of reference they have been designated the *lower*, *middle* and *upper* insect layers The lower layer shows sedimentational and organic features which suggest that it was laid down close to the shore and that most of its biota was washed into the lake. The matrix and biota of the middle layer, which is highly irregular and characterized by pink partings, were probably transported to the water by violent dust storms. The upper layer is highly argillaceous, and was deposited under strongly saline conditions; insects are rare but they are very well preserved.

Midco Salt Lake was essentially a playa, barren of life except for algae and Conchostraca (Crustacea). There is no evidence that insects, either nymphs or adults, lived in the water of the lake itself. Most insects preserved in the limestone were presumably carried to the water by gales or floods and were therefore not all derived from the local environment. Thus, the aquatic nymphs which are abundant at a few localities (e. g. loc. 15) were almost certainly brought to the lake intermittently by small streams

in a flooded condition. Plants did not grow near the lake; they are sparsely represented in the beds by fragments of leaves or wood, which were also carried to the water by winds and floods.

The foregoing account describes a very different environment from that existing in the vicinity of Insect Hill in Kansas, when the Elmo limestone was formed. According to Dunbar (1924) this bed was deposited in a fresh-water lake or lagoon, derived from an earlier swamp Plants apparently grew close to the water's edge and although most insects were driven into the water by occasional storms, some lived in the water during their nymphal stages. The Elmo Lake was much smaller than the Midco and consequently presented less diverse environmental conditions. Nevertheless, the two lakes were only about 140 miles apart and apparently nearly contemporaneous

The Xiphosura and Conchostraca which Dr Raasch and I collected in the Midco beds have already been studied and described by Professor P E. Raymond (1945, 1946). Three specimens of Xiphosura, found in the lower layer at locality 15, represent two new species of a new genus· *Anacontium carpenteri* Raym. and *A breve* Raym. The genus belongs to the family Euproöpidae, previously known only from Carboniferous strata. The Conchostraca include seven species, all new and representing three families. Lioestheriidae, with *Lioestheria raaschi* Raym , *Pseudestheria brevis* Raym , *Ps plicifera* Raym , and *Ps. rugosa* Raym., Limnadiidae, with *Pemphicyclus laminatus* Raym. and *Palaeolimnadiopsis carpenteri* Raym.; and Leaiadidae, with *Leaia reflexa* Raym. The occurrence of the Leadidae is especially interesting, since the family has previously been known only from Carboniferous strata *Pseudestheria plicifera* is also noteworthy, for it is the species which occurs, though very rarely, in the Elmo limestone. Apart from the occurrence of insects, the extraordinary abundance of Conchostraca is the most striking characteristic of the Midco fauna. Although these Crustacea were probably unable to develop prolifically in the hypersaline water of the Lake, they presumably became well established after cyclical inflow of fresh water, which undoubtedly occurred in the spring of certain years. Subsequent evaporation of much of the water in the Lake would cause a reversion to hypersalinity and result in the death of masses of adult Conchostraca. Their eggs, however, presumably survived through this period and hatched when the water again became habitable.*

Very little can be said at this time about the Midco insect fauna It obviously includes the same orders as that at Elmo, as well as many of the genera and a few species; but it also contains families which are not known from the Elmo limestone and even several which have previously been found only in Carboniferous rocks. This is particularly interesting in view of the Carboniferous affinities of some Midco Xiphosura and Conchostraca A satisfactory comparison of the insects of the two beds cannot be made until studies of both faunas have been completed.

Because of the extent of the Midco insect beds, our collections were made at widely scattered localities in the area. Furthermore, since these localities undoubtedly represent some diversity of environments, record has been kept, by number, of the locality at which each fossil was collected. The approximate site of the localities is given in the accompanying table. Similar record has been kept of the layers of the insect bed in which the specimens were found, the letters L, M, U, indicating the lower, middle and upper layers respectively. The present collection of Midco insects is presumably by no means representative of the fauna. My original project of making a series of annual trips to the beds, although temporarily halted by the war, will now be carried out until a more extensive collection has been secured.

Before closing these introductory remarks, I wish to acknowledge the aid of the Geological Society of America, which financed in part the 1940 collecting trip with a grant from the Penrose Bequest (Project Grant 335–40). All who are interested in fossil insects are deeply indebted to Dr. Raasch for his discovery of one of the most important insect-bearing beds known; and I, in particular, am indebted to him for his indispensable help as a technical field assistant. I am also obligated to Mr. F. H. Ward, of Ward's Natural Science Establishment, for his part in introducing me to Dr. Raasch's discovery. Finally, both Dr. Raasch and I owe thanks to our friends in Noble County who allowed us to collect without restraint on their property.

The following pages deal with the Midco insects belonging to the Orders Megasecoptera, Protodonata and Odonata. Other orders will be treated in subsequent papers in this series.

* This is suggested by Sars' experiments (1896) on the eggs of Limnadia, which developed normally after resting at least seven years in dried mud. From other observations he concluded that these eggs, in order to be able to develop at all, need to lie dry for several successive years.

Loc. 1. Sw. corner, Sec. 28, T23N, R1W.
Loc. 2. Sw. ¼ of Sw. ¼, Sec. 20, T23N, R1W.
Loc. 3. Nw. ¼ of Nw. ¼, Sec. 4, T23N, R1W.
Loc. 4. Se. ¼ of Ne. ¼, Sec. 34, T22N, R1W
Loc. 5. Sw. ¼ of Se. ¼, Sec. 4, & Nw ¼ of Ne. ¼, Sec. 9, T23N, R1W.
Loc. 6. Sw. ¼ of Sw. ¼, Sec 10, T23N, R2W.
Loc. 7. Ne. ¼ of Nw. ¼, Sec 34, T22N, R1W
Loc. 8. Nw. ¼ of Nw ¼, Sec. 34, T22N, R1W.
Loc. 9. Roadcut ½ mile south of Ne. Corner, Sec. 33, T21N, R1W.
Loc. 10. Ne ¼ of Nw. ¼, Sec. 28, T22N, R1W.
Loc. 11. Se ¼ of Sw. ¼, Sec 22, T22N, R1W.
Loc. 12. Ne. ¼ of Se ¼, Sec. 34, T22N, R1W.
Loc. 13. Ne. ¼ of Sw. ¼, Sec. 13, T23N, R2W.
Loc. 14. Sw. ¼ of Ne. ¼, Sec 14, T23N, R2W.
Loc 15. Sw. ¼ of Nw. ¼, Sec. 2, T21N, R1W.
Loc. 16. Ne. ¼ of Ne. ¼, Sec. 33, T22N, R1W.

Table 1 Midco Insect Bed.

1940 Localities by sections, ranges, and townships, in Noble Co., Oklahoma

Order MEGASECOPTERA

This order is represented in the Midco collection by eighteen species, which I have assigned to eight genera and five families. The Elmo beds in Kansas, which are also of Wellington age, have so far yielded eleven species referable to five genera and four families. These figures indicate that the order Megasecoptera is more abundantly and diversely represented in the Midco fauna than in the Elmo fauna They are especially significant since about twice as many specimens of insects have been collected at Elmo as in the Midco beds

The families present in the Midco member include all those found in the Elmo fauna and in addition the family Bardohymenidae The occurrence of the latter is of much interest, since it contains species closely related to *Aspidothorax*, from the European Carboniferous. All the Megasecopterous genera known from Elmo are likewise included in the Midco fauna, with the single exception of *Permohymen*. Three new genera are represented in the Midco beds, as well as one genus (*Sylvohymen*) described from the Russian Permian, but not known from Elmo. Four of the eighteen species from Oklahoma are apparently identical with those from Elmo; the others are new.

Some of the new species, especially the Martynoviids, furnish interesting evidence bearing on the interpretation of the wing venation of the Megasecoptera and its phylogenetic importance It is now apparent that the order was a much larger and diversified group than has previously been supposed, with at least two distinct phylogenetic lines within the order. The evidence for these statements and other conclusions which I have reached will be discussed below, after the description of the fossils

Family Elmoidae

This interesting family has previously been known only from one species, *Elmoa trisecta* Till., from the Kansas Permian. In the Oklahoma collection there are six specimens representing two new genera and four new species, in addition to *trisecta*. This material provides us with additional information about the family and requires slight modification of the characteristics previously suggested for the group (Carpenter, 1943). In the new specimens, some of which are splendidly preserved, the stem of R is obviously free from the stem of CuA. This condition undoubtedly existed in *Elmoa*, but the flattening of the convexities and concavities at the base of the wing in the specimens of *Elmoa* presumably caused the apparent fusion of the two stems All well-preserved specimens of Elmoidae have the stem of R very strongly convex, that of CuP strongly concave The stem of CuA, which joins CuP only at the very base of the wing, is situated on the steeply inclined membrane between R and CuP. Also in all the new species there are at least three anal veins, instead of two, as in *Elmoa*. This is an especially important characteristic, not elsewhere known among the Megasecoptera.

The outstanding characteristics of the Elmoidae are (1) the independence of the stems of R and CuA, (2) the absence of coalescence between Rs and MA, and (3) the proximal convergence of the strongly convex CuA and R, forming an angle bisected by stem of M The last characteristic is present also in the Martynoviidae and Asthenohymenidae.

The family Elmoidae, especially as represented by the new genus *Parelmoa*, appears to have a relatively generalized venation and to have several venational features suggestive of the Palaeodictyoptera. Indeed, arguments for placing *Parelmoa* in the Palaeodictyoptera could readily be advanced; but any such assigment would involve not only *Elmoa*, but the Martynoviidae and Asthenohymenidae. Also concerned in this question is the Carboniferous genus *Diaphanoptera*, a detailed account of which is being published elsewhere.[1]

[1] Studies on Carboniferous Insects from Commentry, France. Part II (in preparation).

Elmoa trisecta Till.

Elmoa trisecta Tillyard, 1937, Amer. Journ Sci., **33:** 84. Carpenter, 1943, Proc. Amer. Acad , **75:** 56.

There is a single specimen (4736ab) of this in the material from the Midco beds; it was collected at locality 8-M, and consists of the proximal third of a wing. Its venation, as far as known, is identical with that of the Kansan specimens.

Parelmoa, new genus

Related to *Elmoa.* Fore wing: Sc terminating on costal margin slightly beyond mid-wing, i. e., just beyond first fork of Rs; Rs arising nearer the base than in *Elmoa,* with three branches, and joined by a cross-vein to MA basally (as in *Elmoa*), but the cross-vein is nearer the origin of MA and further from the origin of Rs than it is in *Elmoa;* MA simple, MP forked, CuA and CuP unbranched; 1A well developed, extending to midwing and with three branches; 2A and 3A present, the latter branched from the base. Cross-veins numerous. Hind wing. Sc closer to R than in the fore wing; anal veins apparently as in fore wing

Genotype: *Parelmoa revelata,* n. sp.

This genus differs from *Elmoa* chiefly in having a longer Sc and greater development of anal veins.

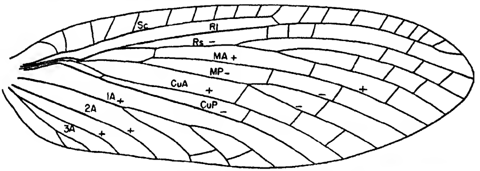

FIGURE 1. *Parelmoa revelata,* n. sp Drawing of fore wing (holotype). Sc, subcosta (concave); R1, radius (convex); Rs, radial sector (concave), MA, anterior media (convex), MP, posterior media (concave); CuA, anterior cubitus (convex); CuP, posterior cubitus (concave); 1A, 2A, 3A, anal veins

Parelmoa revelata, n. sp.

Figure 1; plate 2, figure 2

Fore wing: length, 15 mm , width, 5 mm ; broadest across the middle or not much beyond, Sc connected to R1 by a distal cross-vein, R2 + 3 long, unbranched, R4 + 5 forking slightly after its origin, MP forked at about the level of first fork of Rs; 1A forked at about half its length and again somewhat beyond this; 2A simple; 3A giving rise distally to a posterior branch, which is in turn twigged distally (probably an individual trait). Cross-veins are numerous but weak, except those at base of costal space. The distribution of preserved cross-veins in the type indicates that others discernible in the specimen were originally present. Hind wing unknown.

Holotype: No. 4822ab, Museum of Comparative Zoology, collected in the Midco insect bed (loc. 15-L), Noble Co., Oklahoma, by F. M. Carpenter and G. O. Raasch. The specimen is a complete and splendidly preserved fore wing.

Parelmoa radialis, n. sp.

Figure 2

Fore wing: length, 15 mm.; width, 5 mm. Shape and venation (as far as known) as in *revelata,* except that R4 + 5 is unbranched, and R2 + 3 divides shortly after its origin. There is a suggestion of a terminal twig on R2, but this is almost certainly an individual trait. Only a few cross-veins are present in the type, outside of the costal space. The anal veins are unknown. Hind wing: length, 12 mm.; width, 4 mm ; costal margin and stem of R straighter basally than in fore wing (as is true of *Elmoa*); venation otherwise like fore wing, including the branching of Rs. 1A and 2A unbranched; 3A branched much as in *revelata.* Cross-veins weakly preserved in the type and those of the costal space are not discernible.

Holotype. No. 4825, Museum of Comparative Zoology, collected in the Midco insect bed (loc. 15-L), Noble Co., Oklahoma, by F. M. Carpenter and G O. Raasch This consists of a nearly complete hind wing, moderately well preserved. Paratype. No. 4824, (loc. 8-M), Museum of Comparative Zoology, consisting of a well preserved fore wing, lacking the anal area.

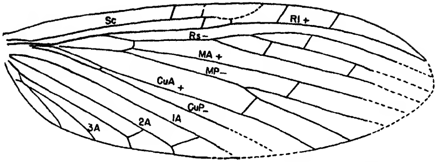

FIGURE 2. *Parelmoa radialis*, n. sp. Drawing of hind wing (holotype) Lettering as in figure 1.

This species is distinguished from *revelata* on the basis of the structure of Rs and 1A. Although the anal veins are lacking in the paratype (fore wing), I have associated this with the holotype (hind wing) because of the similar form of Rs. The difference in branching of Rs in the two species might, of course, be due to individual variation. However, in the seven known specimens of the *Elmoa trisecta* from the Elmoa beds, the branching of Rs is strikingly constant and I assume the same stability for *radialis* and *revelata* The branching of 1A is also markedly different in *radialis* from what it is in *revelata*, but of course this vein is known only in the hind wing.

Parelmoa obtusa, n. sp.

Figure 3

Fore wing: length, 17 mm., width, 5.5 mm ; broadest in distal third of the wing; apex broadly rounded; costal margin not so convex as in *revelata* and *radialis;* Sc somewhat longer than in the latter two species; R2 + 3 forked, R4 + 5 unbranched, 1A with a terminal fork; 2A unbranched, 3A with a forked posterior branch. Cross-veins apparently fewer than in *revelata*, many arranged obliquely Hind wing unknown.

Holotype· No. 4823 ab, Museum of Comparative Zoology; collected in Midco insect bed (loc. 15-L), Noble Co , Oklahoma, by F. M. Carpenter and G. O. Raasch. This is a complete and well preserved fore wing.

Pseudelmoa, new genus

Related to *Parelmoa* Fore wing: Sc extending far beyond level of first branch of Rs; Rs with at least five terminal branches; Rs arising further proximad than in *Parelmoa;* MP forked; three anal veins, 1A long, extending to about mid-wing; cross-veins about as numerous as in *Parelmoa*. Hind wing unknown.

Genotype· *Pseudelmoa ampla*, n sp.

This genus is notable for the length of Sc and the numerous branches of Rs.

Pseudelmoa ampla, n. sp.

Figure 4

Fore wing. length (as preserved), 20 mm.; width, 6 mm ; estimated length, 22 mm ; costal margin not convex; Sc terminating beyond fork of R2 + 3; MA apparently arising near mid-wing but a weak and probably adventitious vein at this point makes the origin uncertain; 1A with a distal fork; cross-

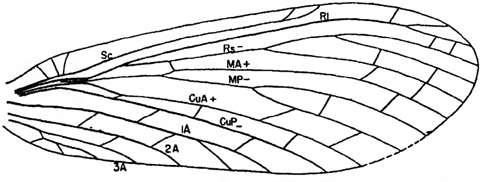

FIGURE 3. *Parelmoa obtusa*, n. sp. Drawing of fore wing (holotype). Lettering as in figure 1..

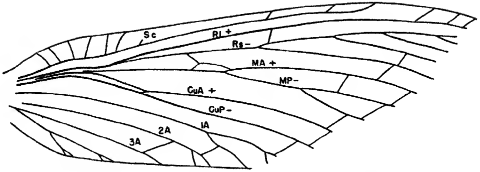

FIGURE 4 *Pseudelmoa ampla*, n. sp Drawing of fore wing (holotype) Lettering as in figure 1

veins as shown in figure though probably not all are discernible. Hind wing unknown

Holotype: No. 2826ab, Museum of Comparative Zoology, collected in the Midco insect bed (loc 15-L), Noble Co, Oklahoma, by F. M. Carpenter and G. O Raasch. This consists of a well preserved fore wing, lacking the distal portion.

Family BARDOHYMENIDAE

This family was erected by Zalessky (1937) for *Bardohymen magnipennifer* from the Permian of Russia. Since the unique specimen representing that species consisted of the distal half of the wing only, the family could not be satisfactorily defined The collection from Oklahoma contains a complete wing of a species (*Calohymen permianus*, n sp) obviously closely related to *Bardohymen* The family is therefore redefined here with the aid of the information now at hand. We do not, of course, know for certain that the proximal half of the wing of *magnipennifer* is like that of the new species, should it turn out to be very different, a new family will be needed for *Calohymen* In the Midco collection there is also an incomplete wing of a species apparently belonging to the genus *Sylvohymen*, which was described by Martynov from the Russian Permian and tentatively referred to the family Bardohymenidae.

The Bardohymenidae were larger than the Protohymenidae. Their venation was much like that of the Carboniferous Aspidothoracidae The costal space was narrow, R1 being submarginal, at least in the distal half of the wing. Sc is not clear distally, it apparently extended well beyond the origin of Rs, which arose not far from mid-wing and gave rise to at least three branches, M arose at the base of the wing and though close to R, apparently retained its independence from R (as in the Aspidothoracidae) and diverged away from R well before the origin of Rs; MA was not anastomosed with Rs; Cu was apparently anastomosed with the stem of M for a short interval; CuA was not anastomosed with M or MP; a single anal vein was present, formed as in *Aspidothorax;* cross-veins were numerous but there were not more than twenty-five in all. The differences between the fore and hind wings have not been determined, probably the wings were nearly homonomous, as in *Aspidothorax* and most other Megasecoptera.

The closest relatives of this interesting family are the Aspidothoracidae from the Carboniferous of Commentry Zalessky placed Bardohymenidae in the Suborder Protohymenoptera, presumably because of the proximity of Sc and R1 to the margin, but the family has much more in common with the Aspidothoracidae than with Protohymenidae or its relatives This is one of the several examples, noted in this paper, of the occurrence of Carboniferous types in the Midco fauna

Calohymen, new genus

Related to *Bardohymen*. Sc apparently terminating beyond mid-wing; R1 not forked distally; Rs with three branches; MA, MP, CuA and CuP unbranched, two distinct rows of cross-veins, even the outer row being remote from the posterior margin of the wing

Genotype *Calohymen permianus*, n sp.

Calohymen permianus, n sp

Figure 5

Wing. length, 25 mm.; width, 6 5 mm. Costal margin straight for the proximal two-thirds of the wing, then broadly curved, apex slightly rounded; posterior margin only slightly curved; wing broadest at the level of the origin of R4 + 5; R1 diverging slightly away from the margin above the branches of Rs, connected to the margin by two cross-veins (at least in type); no pterostigmal thickening visible;

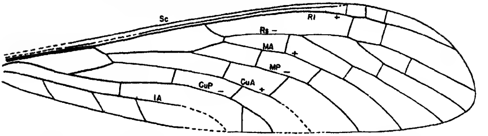

FIGURE 5 *Calohymen permianus*, n sp Drawing of holotype. Lettering as in figure 1

Rs arising slightly before mid-wing; R4 + 5 only a little longer than R3; two long cross-veins between Rs and R1; MA arising slightly proximad of the origin of Rs, connected to Rs by a short cross-vein; CuA arising well before the divergence of M from R1 and connected to M by an oblique cross-vein, CuP has a slight terminal branch, which is probably formed by an oblique cross-vein (as in *Aspidothorax*), 1A with four veinlets leading to the hind margin; between all main veins (except CuP and 1A) there are two cross-veins arranged as shown in figure 5.

Holotype: 4687ab, Museum of Comparative Zoology; collected in Midco insect beds (loc 15-L), Noble Co., Oklahoma (F. M Carpenter and G. O. Raasch) It consists of a well preserved wing, complete except for a small piece along the posterior margin at the end of CuA

This species is of much interest because of its resemblance to *Aspidothorax*, a drawing of which is included here (figure 6.) [2] Unlike the condition in Protohymenidae, etc, MA is free from Rs and CuA is free from M. So close is *Calohymen* (and presumably *Bardohymen*) to *Aspidothorax* that it is difficult to find many differences between the two. Sc is possibly slightly longer in *Aspidothorax* than in *Calohymen;* MP is deeply forked in *Aspidothorax* but simple in *Calohymen;* and the number of cross-veins in *Aspidothorax* is approximately twice that in *Calohymen.* These differences are probably sufficient to justify the retention of the family Bardohymenidae, but they are much less than have previously been found between Permian and Carboniferous Megasecoptera.

[2] An account of the structure and relationships of *Aspidothorax* is included in my revisional study of Commentry insects, Part II, now in preparation.

Genus *Sylvohymen* Martynov

Sylvohymen Martynov, 1940, Trav. Inst. Paleont **11: 10.**

This genus was based on a distal fragment of a wing (*robustus*) and placed by Martynov in the family Bardohymenidae, although its relationships will not be certain until more of the wing is known In the Midco collection there is a distal fragment of a wing which resembles that of *robustus* to a remarkable degree. I therefore place the species in *Sylvohymen* until more of its structure is known

Sylvohymen ingens, n sp.

Figure 7

Wing: length of fragment, 18 mm ; width, 9 mm ; estimated length of complete wing, 50 mm Costal margin thickened distally, as far inward as R1; R1 diverging away from the margin only very slightly near the apex, with three short cross-veins between it and the margin, Rs with 4 branches, R2a, R2b, R3, and R4 + 5; a long cross-vein between R1 and

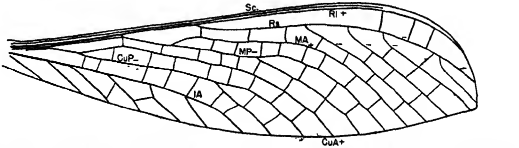

FIGURE 6. *Aspidothorax* sp. (Carboniferous of Commentry, France). Original drawing of fore wing, based on specimens in the Muséum National d'Histoire Naturelle, Paris. Lettering as in figure 1

the fork of R2 + 3 and a shorter cross-vein near the apex between R1 and R2; one cross-vein between each branch of Rs; two between R4 + 5 and MA

Holotype. No. 4673ab Museum of Comparative Zoology; collected in Midco insect beds (loc. 3), Noble Co., Oklahoma (F. M. Carpenter and G. O Raasch). This consists of the distal part of a wing Since the preserved part does not include the origin of R4 + 5, it probably represents only about a third of the entire wing. This species was apparently only a little larger than *robustus*, which Martynov estimated to have a wing length of 40 mm.

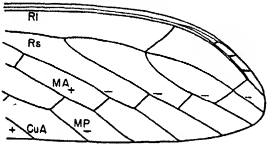

FIGURE 7 *Sylvohymen ingens*, n. sp Drawing of holotype. Lettering as in figure 1.

The similarity between the venation of *robustus* and that of *ingens* is very striking, though of course the proximal parts of the wings may not have been so much alike. As Martynov points out, *Sylvohymen* (as far as known) is closer to *Bardohymen* than it is to any other Megasecoptera Additional and more nearly complete specimens will be needed to make certain of this; if it should turn out that Rs is anastomosed with MA, as it is restored in Martynov's figure, the systematic position of the genus will be very different.

Family Martynoviidae

This family has previously been known from the lower Permian of Kansas (Elmo), where it is represented by the genus *Martynovia*, with two species (*insignis* Till. and *protohymenoides* Till) In the Midco beds there are four new species, described below; one of these belongs to *Martynovia*, the others to new genera.

Genus *Martynovia* Till.

Martynovia Tillyard, 1932, Amer Journ. Sci., **23:** 13; Carpenter, 1943, Proc. Amer. Acad Arts Sci., **75:** 58

In my discussion of this genus (1943), I stated that the radial sector included from 3 to 5 branches; since the number of branches of Rs in the new species is seven, the definition of the genus is now altered to that extent. In all other respects (so far as known) the following species conforms to the generic definition

Martynovia longipennis, n. sp.

Figure 8

Fore wing length, 20 mm ; width, 4.5 mm. Costal margin slightly concave basally, but with a distinct bulge above origin of MA; rest of margin with slight convexity, posterior margin smoothly convex, base of wing more narrowed than in *protohymenoides*; apex of wing unknown; at least two prominent cross-veins in costal space, at the level or origin of CuP; Sc weak distally, terminating at about mid-wing; R1 also very weak apically; both Sc and R1 apparently end in a faint pterostigma, as in *M. protohymenoides*, 4 or 5 well developed cross-veins between Rs and R1; Rs with seven branches, although this number is probably slightly variable in individuals; MA anastomosed for a short distance with Rs, much as in *insignis*, M arising from the stem of R in the manner characteristic of the genus, i. e., at the point of divergence of CuA from the same stem; CuP and 1A are like those of *protohymenoides*, but 2A is very short, having almost been lost by the narrowing of the base of the wing, two cross-veins present between MA, MP, CuP, and 1A, and probably two also between the branches of Rs, though they are not preserved in the fossil.

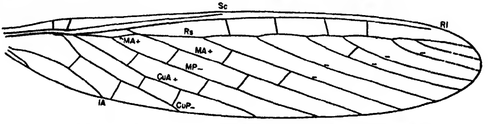

FIGURE 8. *Martynovia longipennis* n. sp. Drawing of fore wing (holotype). Lettering as in figure 1.

Hind wing unknown.

Holotype: No. 4676, Museum of Comparative Zoology; collected in the Midco insect beds (loc 16), Noble Co., Oklahoma (F. M. Carpenter and G. O. Raasch). This is a well preserved wing, complete except for the very apex. The narrowness of the wing, especially basally, indicates that it is a fore wing.

Although this species has much longer wings than the genotype (*insignis*), its venation is essentially the same as that of the latter. In wing shape *longipennis* is similar to *protohymenoides*, but the greater number of branches of Rs and the very short 1A are obvious differences The pterostigma of *longipennis* is not indicated by coloration; but the faintness of Sc and R1 distally shows that the pterostigma was present and formed essentially as in *protohymenoides*.

Eumartynovia, new genus

Fore wing: long and moderately slender Costal space of normal width basally, but narrowed above end of Sc, at which point there is a pronounced bend in the margin of the wing; Rs arising almost at mid-wing and giving rise to four branches, M arising from the stem of R + M at the point of origin of CuA, as in *Martynovia;* MA anastomosed with Rs and also with R, well before the origin of Rs, MA, MP, CuA, CuP, and the anals all unbranched, cross-veins few in number. Pterostigma very long and colored, but not very thick.

Hind wing unknown.

Genotype: *Eumartynovia raaschi*, n sp.

This genus, although close to *Martynovia*, is distinguished chiefly by having the costal margin distinctly indented at about mid-wing, and by having MA coalesced with the radius well before the origin of Rs.

Eumartynovia raaschi, new species

Figure 9; plate 2, figure 1

Fore wing: length, 22 mm ; width, 5 mm. Costal margin smoothly arched from the base to about the middle of the wing; unevenly arched from mid-wing to apex; apex pointed; posterior margin smoothly curved; three pterostigmal cross-veins in costal area, two of them near the level of the origin of CuP, the other near the end of Sc; Sc ending at about mid-wing, slightly beyond the level of the origin of Rs, a heavily pigmented pterostigma extends from the end of Sc to slightly beyond the apex of the wing; this is confined to a narrow strip for most of its length, but near the fork of R2, it extends medially as far as R2 and R2a; between Rs and R1 there are three long cross-veins, and between the branches of Rs, as well as between MA, MP, CuA, CuP, and 1A there are two cross-veins, the free basal piece of MA is short, MA anastomosing with R1 so that R + MA is nearly equal in length to MA + Rs; 1A well developed, 2A short

Holotype. No. 4680ab, Museum of Comparative Zoology; collected in the Midco beds (loc. 15-L), Noble Co , Oklahoma (F M Carpenter and G. O Raasch) This species is named for Gilbert O Raasch, who was first to find insects in the Midco strata. The holotype specimen is a strikingly preserved fore wing (plate 2, fig. 1).

This insect is remarkable for the long pigmented pterostigmal area The species of *Martynovia* also have a long pterostigma, but so far as known in none of them is it as long or as heavily pigmented as in *raaschi*

Phaneroneura, new genus

Allied to *Martynovia* Fore wing slender or moderately broad. Costal space of moderate width basally, narrowed at the level of origin of Rs, costal margin straight or nearly so, only one cross-vein apparently present in costal space, Rs arising just before mid-wing, with two or three branches, M arising from the stem of R + M at the point of separation of CuA from R + M, as in *Martynovia;* MA separating from MP very shortly after the origin of M, and anastomosing immediately with R, the free basal piece of MA being very short; R + MA longer than Rs + MA; MA, MP, CuA, CuP

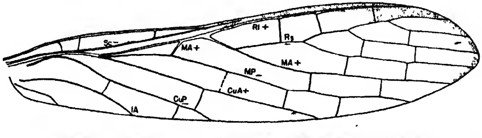

FIGURE 9. *Eumartynovia raaschi* n. sp. Drawing of fore wing (holotype). Lettering as in figure 1.

and anals all unbranched; cross-veins very few; pterostigma apparently formed as in *Martynovia*, unpigmented and weak.

Genotype: *Phaneroneura martynovae*, n sp

All the specimens of this genus being isolated wings, we have no knowledge of the differences, if any, between the fore and hind wings. Although some of the wings are slightly broader basally than others, none show the obvious differences in shape exhibited by the fore and hind wings of *Martynovia*

This genus contains the most highly specialized Martynoviids so far known The outstanding characteristics of the genus are the extensive anastomosis of MA with R, before the origin of Rs, and the reduction in the number of cross-veins and branches of Rs

Phaneroneura martynovae, n. sp

Figure 10

Fore wing. length, 12 5 mm.; width, 3 mm. Costal margin nearly straight, with only a slight indication of concavity, apex narrowly rounded, costal space narrow at base, widest at level of origin of CuA; Sc weak distally, ending about mid-wing; pterostigma indicated only by a slight thickening of membrane; Rs forked twice, forming three branches, a strong cross-vein is present between Rs and R1 at each of these forks, R + M longer than MA + Rs; CuA nearly straight; CuP diverging abruptly away from the stem of Cu, 1A long, curved, 2A very short Two cross-veins are present between most of main veins and branches of Rs, their arrangement slightly variable in individuals.

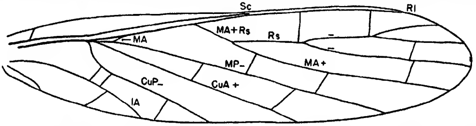

FIGURE 10. *Phaneroneura martynovae* n. sp. Drawing of fore wing based mainly on holotype. Lettering as in figure 1

Holotype: No. 4675 ab, Museum of Comparative Zoology, collected in Midco insect beds (loc. 15-L), Noble Co., Oklahoma (F. M. Carpenter and G O. Raasch). This is a well preserved and complete wing.

Paratypes: No. 4738, Museum of Comparative Zoology same collecting data as holotype, except for quarry no. 8-M. This specimen is also a complete wing, with a venation almost identical with that of the holotype. It may be a hind wing, however, since the posterior margin is slightly more rounded basally, and the origins of M, CuP and CuA are nearer the base than in the holotype. No. 4670, same collecting data (loc. 15-L); this is a nearly complete wing, lacking the proximal fifth of the wing.

In addition to these, there are three more poorly preserved specimens. No. 4739 (loc. 15-L); no. 4740 (loc. 8-M); and no. 4677ab (loc. 15-L). The last specimen consists of the distal half of a wing 3 5 mm. wide; this may be a hind wing.

This species has been named for Olga Martynova, who worked on fossil insects for many years with her husband, Dr. A B. Martynov, and who has continued her studies independently since his death in 1938.

Phaneroneura reducta, n. sp.

Figure 11

Fore (?) wing. length, 7 mm.; width, 2.5 mm Costal margin almost straight, as in the genotype; apex broadly rounded; posterior margin strongly and evenly curved, costal space relatively broader above origin of CuA than in *martynovae* and more abruptly narrowed at end of Sc; Sc terminating at the middle of the wing; pterostigma very weakly indicated by slight thickening of membrane; Rs with but one fork though in the holotype only there is a weak incomplete vein running from R2 + 3 towards the end of R1; one cross-vein between Rs and R1, at the fork of Rs; MA + R much longer than MA + Rs; CuP not so abruptly diverging from the base of Cu as in *martynovae*, arising from the stem just proximad to the point of separation of MP and CuA (at least in holotype); 1A long; only one cross-vein between the main veins of the wing, and none at all between R2 + 3 and R4 + 5.

Holotype: No 4733ab, Museum of Comparative Zoology; collected in Midco insect beds (loc. 15-L), Noble Co., Oklahoma (F. M. Carpenter and G. O. Raasch). This specimen consists of an excellently preserved wing, complete except for the very base.

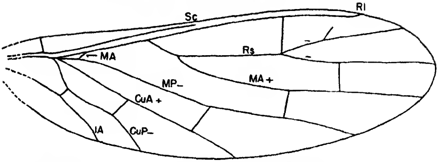

FIGURE 11 *Phaneroneura reducta*, n sp. Drawing of wing, based mainly on holotype Lettering as in figure 1

Paratypes· No. 4737ab, Museum of Comparative Zoology; same collecting data (loc. 15-L); this is also nearly a complete wing, lacking only the very base; its venation is identical with that of the holotype, except for the absence of the adventitious vein from R2 + 3 No. 4741ab, same data (loc. 15-L); this is a well preserved wing lacking more of the base than the other specimens, it is 6 mm long and 2 5 mm. wide, R2 + 3 lacks the adventitious vein.

The three specimens on which this species is based may be hind wings and I have considered the possibility that they might represent the hind wing of *martynovae*. However, in none of the other Martynoviidae or in fact in none of the Megasecoptera as a whole so far known, do the fore and hind wings differ in venation, except of course for slight contour of the veins, etc. The specimens of *reducta* are distinctly different in venation from those of *martynovae:* Rs has only one fork instead of two, and there is only one cross-vein between all main veins, instead of two. Furthermore, the wings of *reducta* are only about half the size of those of *martynovae*, a difference which is not known to occur between the fore and hind wings of Megasecopters. It is my conviction therefore, that even if these specimens are hind wings, they do not belong to *martynovae*.

Family Protohymenidae

This family has previously been found in the Permian of Kansas and Russia. In the Oklahoma collection it is represented by four new species and one (*Protohymen readi* Carp.) already described from the Elmo limestone Before discussing these species, however, I wish to consider certain venational aspects of the Protohymenidae which need clarification. The homologies of the wing veins of the Carboniferous Megasecoptera have been generally agreed upon, for although in some genera there is slight venational anastomosis, the identity of all main veins is obvious. This is also true of the venation of most Permian genera, in spite of the increased amount of anastomosis, and the interpretation which I proposed (1931) for such specialized genera as *Protohymen* and *Permohymen* has been generally accepted (Tillyard, 1936, p. 447). Martynov, although accepting this view in relation to other views, advocated a very different interpretation of the structure of Rs. He believes that the condition of the radius in *Eohymen* Mart. (1937) and *Aspidohymen* Mart. (1930) represents an early stage in the evolution of this vein, ultimately leading to its structure in the Protohymenidae. In *Aspidohymen*, according to Martynov, Rs divides early into a distal branch (Rsds) and a proximal branch (Rspr), the former arises from the stem of Rs, then anastomoses with R1, only to branch off again distally. In *Eohymen* the anastomosis of Rsds with R1 takes place further proximally, so that it appears to arise directly from R1 The amount of anastomosis of Rsds with R1 has increased during the subsequent evolution of the Protohymenoptera, in *Protohymen*, the origin of Rsds from R1 is at the level of the pterostigma; and in *Asthenohymen* the coalescence is complete. It is on the basis of the coalescence of these veins that Martynov separates the Protohymenoptera from the Order Megasecoptera, in which there has been no such anastomosis.

I have two main objections to this proposal. In the first place, the evidence provided by *Aspidohymen* and *Eohymen* is very questionable. *Aspidohymen* is known by two species, *extensus* Mart. (1930, 1937) and *chopardi* Zal. (1937) from the Russian Permian [3] Both of these species are based on unique wings, each lacking the proximal third. We have no knowledge, therefore, of the origin of any main veins except Rs. The part of the venation that is known is different in several respects from

[3] Only *extensus* was known to Martynov, *chopardi* having been described just before his death.

that of the Protohymenidae and related families. In both species of *Aspidohymen*, for example, MA is forked (convex),[4] though it is simple in all other families which have been placed in the Protohymenoptera; and Rs (Rspr of Martynov) is unbranched, another feature not occurring in other Protohymenoptera [5] Furthermore, I am convinced that Martynov has not correctly homologized certain veins in Aspidohymen He does not indicate in his figure of *extensus* whether the distal branch of Rs (Rsds) is convex or concave; probably its nature was not suggested in the poorly preserved type But Zalessky's figure of *chopardi*, which is based on a better fossil shows this vein to be convex (+), not concave. It cannot therefore be a branch of the concave Rs

The genus *Eohymen* is also based on a poorly preserved wing, as indicated by the broken and dotted lines in Martynov's figure (1937, fig. 1). There are many features of the preserved part of the wing which are entirely foreign to the Protohymenidae, etc, such as the double row of cells between certain veins and the remoteness of R from the costal margin. Martynov presents no evidence showing that this wing is actually related to the Protohymenidae, but even if we assume that it is, the gap between it and *Protohymen* is too great for it to be taken as the basis of the explanation of the protohymenid wing

The Protohymenidae, also, furnish evidence which refutes Martynov's theory of the protohymenopterous venation A detailed examination of the pterostigmal area of *Protohymen* shows R1 running along the posterior edge of the pterostigma After giving rise to the vein *a* (figure 12A), it appears to continue for a short distance along the pterostigma (b). A similar condition occurs in all species of the genus, with but slight variation The pterostigmal area of *Permohymen* is obviously of the same general type. Now Martynov identified the vein *a* as the reduced distal branch of Rs (Rsds), but he apparently overlooked the fact that this vein is distinctly convex, as shown in my figure of *permianus* (1930, fig. 1). The convexity of this vein is clearly indicated in all well preserved specimens of *Protohymen*, especially in those of the Midco beds. It can only be R1, therefore, not a part of Rs (concave).

For the foregoing reasons I believe that Martynov's interpretation of the protohymenid venation is based on doubtful evidence and has more facts against than for it. A simpler and more direct explanation of the pterostigmal area in the Protohymenidae was contained in my first paper on the Protohymenoptera (1930) but was overlooked by Martynov The suggestion was made there that the apparent anterior "branch" of R1 (*b* in figure 12) might be a modified cross-vein. An oblique cross-vein actually does occur at this point in many Megasecoptera, though it is usually weakly preserved. A slight change in the angle of inclination of this cross-vein, together with the thickening of the pterostigma, would produce the condition found in *Protohymen*.

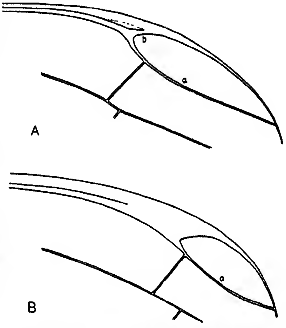

FIGURE 12. Pterostigmal area. *Protohymen venustus*, n. sp. (A); and *Permohymen schucherti* Till. (B), from the Lower Permian of Kansas. For lettering see text.

Genus *Protohymen* Till.

Protohymen Tillyard, 1924, Amer. Journ. Sci. (5) **8**: 114; Carpenter, 1930, Psyche, **37**: 349.

[4] In spite of the convexity of both branches of MA, Martynov identified the anterior one as Rs4.

[5] It should be noted that the nature of the origin of Rs in *Aspidohymen* is uncertain In his original drawing of *extensus* Martynov showed three thin lines above his Rs (at origin of Rs); in my copy of his figure (1930, fig. 4), I omitted the posterior one of these three, being under the impression that two of the lines represented the width of R Martynov called attention to this omission (1937, p 63) and stated that only by omitting that vein would my interpretation be possible However, Zalessky's later figure of *chopardi* shows no such vein there in his better preserved fossil, his drawing being exactly like my copy of Martynov's in that respect.

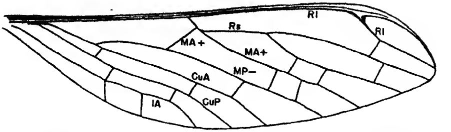

FIGURE 13. *Protohymen curvatus*, n. sp Drawing of fore wing (holotype). Lettering as in figure 1.

Protohymen curvatus, new species

Figure 13

Fore wing: length, 12 mm.; width 3.5 mm.; wing membrane distinctly uneven, the center of the cells of the wing bulging slightly above the edges. Costal margin straight or nearly so, as far as the middle of pterostigma; apex pointed, the tip of the wing more posterior than anterior; posterior margin strongly curved for its entire length, Sc and R1 as in *permianus;* MA anastomosed with Rs for a very short distance only, 1A more remote from the margin than in *permianus*, especially distally; rest of venation essentially as in *permianus*.

The hind wing of this insect is apparently represented by a wing (no. 4665) 14 mm. long and 3.9 mm wide, its shape is like that of the specimen just described, except that the anal margin is more broadly rounded.

Holotype: No. 4666ab, Museum of Comparative Zoology; collected in Midco insect bed (loc 8-M), Noble Co., Oklahoma (F. M. Carpenter & G. O Raasch). This is a complete and splendidly preserved wing Paratype. No. 4665ab, Museum of Comparative Zoology; same collecting data; it is a complete wing with a more broadly rounded anal margin than the holotype, but with an identical venation, except for the position of the cross-veins

In addition to these specimens there are two others, not so well preserved; no. 4686ab (loc 15-L), a hind (?) wing; and no 4683 (loc. 12-M), a fore (?) wing.

Although the wing of *curvatus* resembles that of *permianus* in general form, it differs chiefly in having the posterior margin curved for its entire length, and in having a more sharply pointed apex. The wing membrane of *curvatus* is curiously uneven. The occurrence of this peculiarity in all specimens of *curvatus* shows that it is not an individual condition or the result of unusual preservation Viewed under oblique light the membrane forms a series of shallow bulges and depressions. No other protohymenid possesses this characteristic, except the following new species (*latus*).

Protohymen latus, new species

Figure 14

Hind (?) wing: length, 15 mm.; width, 4 2 mm., wing membrane uneven, as in *curvatus;* shape of wing much like that of *curvatus*, but anal margin more broadly rounded; costal margin nearly straight for most part, but starting to curve somewhat before the beginning of the pterostigma; apex slightly more rounded than in *curvatus;* posterior margin curved for its entire length; Sc and R1 as in *permianus;* MA anastomosed with Rs for a very short interval; 1A very remote from posterior margin, especially distally; a cross-vein present between 1A and margin near base of wing, and one at about the

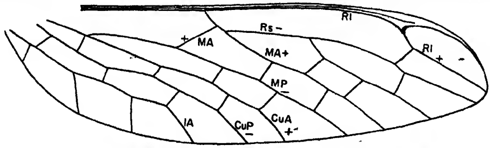

FIGURE 14. *Protohymen latus*, n. sp. Drawing of holotype. Lettering as in figure 1.

same level between CuP and 1A. Rest of venation as in *permianus*.

Holotype. No. 4667, Museum of Comparative Zoology, collected in Midco insect bed (loc. 8-M), Noble Co , Oklahoma (F. M. Carpenter and G. O. Raasch). This is a well preserved wing, complete except for the very base of the costal margin The broadly rounded posterior margin suggests that it is a hind wing and it may eventually turn out to belong to *curvatus*. Both *curvatus* and *latus* have 1A more remote from the margin than it is in any other *Protohymen;* but in *latus* the distance between that vein and the margin is so much greater than in *curvatus* that I believe *latus* to be a distinct insect. The remoteness of 1A from the margin is interesting phylogenetically because it approaches the structure of certain Carboniferous Megasecoptera The proximal cross-veins between 1A and the margin and CuP and 1A may be individual traits only, but I have not seen them in other specimens of the genus.

Protohymen venustus, new species

Figure 15

Fore (?) wing: length, as preserved. 11 mm ; estimated length of complete wing, 12 5 mm , width, 2 8 mm Membrane smooth, as in *permianus;* slenderly oval in shape, costal margin straight only to the proximal end of the pterostigma, the apical curvature beginning at this point; apex acute; posterior margin regularly curved for its entire length; Sc and R1 as in *permianus*, pterostigma not so broad as in *permianus* and *curvatus*, MA coalesced with Rs for a longer interval than in *curvatus;* rest of venation as in *permianus*. Hind wing unknown

Holotype: No. 4668, Museum of Comparative Zoology; collected in the Midco insect beds (loc 15-L), Noble Co , Oklahoma (F. M Carpenter and G O Raasch). This is a splendidly preserved wing, complete except for the very base

This graceful wing differs from that of the described species of *Protohymen* in having the apex of the wing nearly symmetrically curved. In other respects the shape of the wing is more like that of *curvatus* than of *permianus*, but it is narrower proximally and the membrane is decidedly smooth, as in *permianus*.

Protohymen largus, new species

Figure 16

Fore wing: length as preserved, 18 5 mm.; estimated complete length, 21.5 mm.; width, 4.8 mm.; membrane smooth; costal margin straight as far as the beginning of the pterostigma, the apical curvature beginning at that point; apex nearly symmetrical; middle part of posterior margin straight; Sc and R1 as in *permianus*, pterostigma narrower than in *permianus* and *curvatus;* MA anastomosing with Rs for a very short distance; 1A close to hind margin, as in *elongatus* Carp.; rest of venation as in permianus. Hind wing unknown.

Holotype· No. 4671, Museum of Comparative Zoology, collected in the Midco insect beds (loc. 15-L), Noble Co., Oklahoma (F. M. Carpenter and G. O. Raasch). There is a second, more poorly preserved specimen in the collection, no. 4672ab (loc. 12-U); it has a wing length of 15 mm. and a width 13.5 mm.

This is the largest species of *Protohymen* known, its wing expanse was obviously about 45 mm , whereas that of *permianus* was not over 30 mm. In size and shape the wing approaches that of *elongatus* Carp., from Elmo limestone, but the latter has a pointed and very asymmetrically curved apex, whereas that of *largus* is rounded and nearly symmetrical.

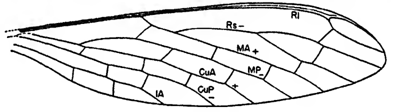

FIGURE 15 *Protohymen venustus*, n sp Drawing of holotype. Lettering as in figure 1.

Protohymen readi Carp.

Protohymen readi Carpenter, 1933, Proc. Amer. Acad **68**: 425

One specimen (no. 4679) which appears to be this species is also included in the Oklahoma collection. The wing is 15 mm. long and 3.5 mm. wide and it lacks only the very base It has the strong crossvein proximal to the pterostigma as in *readi*, as well as the very pointed apex of the latter. This is the only species of the family Protohymenidae in the col-

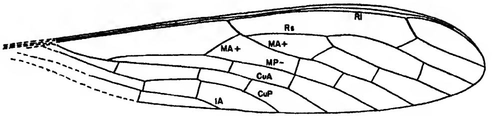

FIGURE 16. *Protohymen largus*, n. sp Drawing of fore wing (holotype). Lettering as in figure 1.

lection at hand which appears to be common to the Elmo and Midco insect beds.

Family ASTHENOHYMENIDAE

These are the most abundant of the Megasecoptera in the Midco beds, so far as the number of individuals is concerned. Slightly more than a hundred specimens are included in the present collection. All of these belong to *Asthenohymen*, the only genus of the family known. A careful study of this material, during which drawings were made of about a third of the specimens, shows that four new species are included, in addition to *A dunbari* Till. and *A pusillus* Till, both originally described from the Elmo beds in Kansas. Because of the uniformity of the venation in this genus, the species have been based almost entirely on the shape and size of the wings It is of course probable that each of these species actually consists of several species, differing from each other in details of body structure, such as genitalia; but we are obviously unable to make such distinctions in the fossils.

Three of the new species described below are unfortunately known only by isolated wings. Presumably, however, the fore and hind wings of these species differ from each other in much the same way as those of *dunbari* and *apicalis*, n. sp., of which complete specimens are known, i. e., the anal margin of the hind wing is slightly more broadly rounded than that of the fore wing and the costal space is somewhat narrower.

Study of the new Asthenohymenidae has convinced me that my previous interpretation of the structure of the radial sector requires modification. In my original account of the venation of these insects (1930), I was led to conclude, by analogy with the Protohymenidae, that MA was coalesced with Rs much as in the latter, except that the free piece of MA had become transversely arranged, more or less at a right angle to Rs, so as to resemble a cross-vein. This interpretation seemed certain to be correct in view of the condition in the Protohymenidae, which were generally considered very closely related to the Asthenohymenidae, and it was accepted by Martynov, Tillyard, and other students of fossil insects. I now believe that, although MA is certainly anastomosed with Rs, the transverse vein mentioned is not part of MA. A comparison of the figures of the Martynoviidae (Figure 17), especially *Phaneroneura*, with those of *Asthenohymen*, will make clear my present interpretation of the latter. There is a striking resemblance between the venation of *Phaneroneura* and that of the Asthenohymenidae; and the differences are in all cases due to specialization on the part of *Asthenohymen*, except for the number of cross-veins. The most significant feature of the Martyoviidae is the nature of the anastomosis between Rs and MA In *M. longipennis*, the amount of coalescence is very slight—in fact MA hardly more than touches Rs In *Eu. raaschi*, MA joins R well before the origin of Rs, and in *Phaneroneura* Rs joins R much nearer the base of the wing. In view of the similarity between the venation of *Asthenohymen* and *Phaneroneura*, it now seems to me that the condition in the latter represents a stage through which the asthenomenid wing has passed. Hence, the real base of MA in *Asthenohymen* has been completely lost by the proximal migration of its origin, and the transverse vein which has previously been thought to be part of MA is really only a cross-vein. In this connection it is noteworthy that in many specimens of *Asthenohymen* the cross-vein indicated is distal of the point of separation of MA from Rs (see Carpenter, 1930, fig. 4). It is of course true that the number of cross-veins in *Phaneroneura* is not quite so large as in *Asthenohymen;* but it is extremely improbable anyway that *Phaneroneura* itself gave rise to the Asthenohymenidae; in all probability a related genus, with a similar structure of Rs and with more cross-veins, was in the direct line of ancestry.

It follows from the foregoing discussion, of course, that the Asthenohymenidae are not at all closely related to the Protohymenidae This is of interest because it substantiates the evidence provided by the position of the wings at rest in the two families.

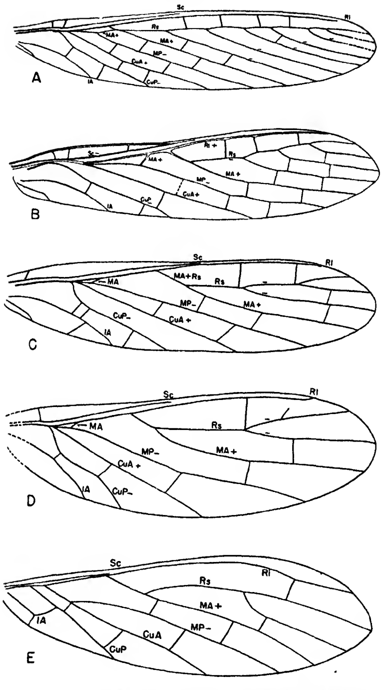

Figure 17. Comparison of venation of Martynoviidae and Asthenohymenidae. A, *Martynovia longipennis*, n. sp. (Martynoviidae), B, *Eumartynovia raaschi*, n. sp. (Martynoviidae); C, *Phaneroneura martynovae*, n. sp (Martynoviidae); D, *Phaneroneura reducta*, n. sp. (Martynoviidae), E, *Asthenohymen apicalis*, n. sp. (Asthenohymenidae). Lettering as in figure 1.

The Asthenohymenidae are known to have been able to fold their wings back over the abdomen at rest, whereas the Protohymenidae were apparently not able to do so. I have discussed this question in my account of the Carboniferous Prochoropteridae (1940), which were also able to fold their wings over the abdomen, and have pointed out there that although at first glance the Asthenohymenidae did not seem at all closely related to the Prochoropteridae, the ability to fold the wings probably did not arise independently in the two families. According to the new interpretation of the asthenohymenid venation, however, the Prochoropteridae and Asthenohymenidae are really very close relatives.

Genus *Asthenohymen* Till.

Asthenohymen Tillyard, 1924, Amer. Jour. Sci. 8: 117; Carpenter, 1939, Proc. Amer. Acad. Arts Sci. 73: 31.

Asthenohymen triangularis, new species

Figure 18

Fore wing: length, 10 mm.; width, 3 mm Proximal part of wing much narrower than the distal part, the wing as a whole being narrowly triangular; costal margin very nearly straight, with a slight bulge above the origin of CuP; apex rounded, the apical curvature beginning at about the pterostigmal cross-vein, posterior margin nearly straight at the middle part, R1 slightly curved away from margin at pterostigma, pterostigma not perceptibly pigmented in type, 2A short, as in *pusillus*, venation in other respects like that of *dunbari*.

Holotype no 4717, Museum of Comparative Zoology; collected in the Midco insect beds (loc. 15-L), Noble Co , Oklahoma (F. M Carpenter and R. O. Raasch). This specimen consists of a complete and splendidly preserved wing; its narrowed anal region indicates that it is a fore wing. In addition to the type there are two other specimens (nos. 4716, 4743) which have a wing-shape like that of the holotype, but the length of the wings is only 6 mm. The wings of this species are more nearly triangular in shape than those of *dunbari* or *pusillus* The width of the wing at the level of the origin of CuA is 1.2 mm., whereas the maximum width is 3 mm., or 2.5 times the basal width. The size of the holotype is greater by about 2 mm. than that of any *dunbari* which I have seen from either the Elmo or Midco beds.

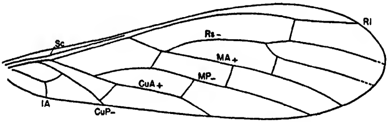

FIGURE 18. *Asthenohymen triangularis*, n sp. Drawing of fore wing (holotype). Lettering as in figure 1.

Asthenohymen apicalis, new species

Figure 19

Fore wing· length, 7.5 mm ; width, 2 5 mm. Proximal part of wing only moderately wider than the basal part; costal margin very nearly straight, with only a slight bulge at the level of the origin of CuP, apex distinctly pointed, the apical curvature beginning before the level of the pterostigmal cross-vein, posterior margin at least slightly curved for its entire length; R1 slightly curved away from margin at pterostigma; pterostigma distinctly darker than the rest of the membrane; 2A short, as in *triangularis*, venation in other respects like that of *dunbari*

Hind wing· similar to fore wing in size, venation and shape (including pointed apex), but anal region is slightly broader.

Holotype: no 4722, Museum of Comparative Zoology; collected in Midco insect beds (loc. 15-L), Noble Co., Oklahoma (F. M. Carpenter and G. O. Raasch). This consists of a splendidly preserved and complete fore wing; no. 4700 (loc. 15-L), a complete fore wing, no. 4705 (loc. 31), a complete fore wing; no. 4710, a complete hind wing; no. 4721 (loc. 15-L), a complete hind wing; No. 4744 (loc. 15-L), a nearly complete fore wing; no. 4745 (loc. 4-L), a complete fore wing, no. 4783 (loc. 8-M), a complete specimen, with parts of all wings, thorax and abdomen, the body is 12 mm. long, which is about one and a half times the length of *dunbari*. The eyes seem more protuberant than in *dunbari*, though preservation may be the cause of this difference.

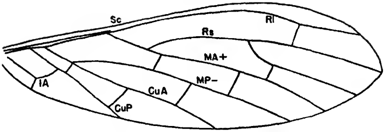

FIGURE 19. *Asthenohymen apicalis*, n sp Drawing of fore wing, based mainly on holotype Lettering as in figure 1.

This species is distinguished from *dunbari* and other described members of the genus by the pointed apex and strongly curved posterior margin. It is the commonest species of Asthenohymen in the Midco beds, next to *dunbari*, there being ten other specimens (nos. 4746 or 4727) in the collection in addition to the types. I have identified specimens nos 4721 and 4710 as the hind wings of this insect because they differ from the holotype just as the fore and hind wings of *dunbari* differ

Asthenohymen parvulus, new species

Figure 20

Fore wing length, 4 3 mm , width, 15 mm Distal part of wing much broader than proximal part; costal margin nearly straight, with a slight bulge over the origin of CuP, distal margin of wing broadly curved, but the very apex is pointed; R1 curved away slightly from the margin at pterostigma; 2A close to hind margin and very short, the curved cross-vein joining it to 1A being fully as long as the part of 2A from the cross-vein to the base; venation in other respects as in *dunbari*.

Hind wing a specimen which I have identified as the hind wing of this species is 4 2 mm long and 1 5 mm wide and has more or less rounded anal margin, in other respects it is similar to the fore wing.

Holotype. No 4747, Museum of Comparative Zoology; collected in the Midco beds (loc 15-L), Noble Co , Oklahoma (F. M. Carpenter and G. O. Raasch) This specimen is a remarkably well preserved and complete fore wing. Paratypes: No. 4698 (loc. 15-L); this is a complete hind wing, well preserved, No 4711 (loc 15-L), a complete fore wing having the same size, shape and venation as the holotype

This insect, which could not have had a wing expanse of more than 10 mm , is the smallest Megasecopteron known The wings are shaped somewhat like those of *triangularis*, but are less than one-half as long and of course have a pointed apex The narrowed anal area of the fore wing has brought 2A closer to the wing margin than in other known species of the genus

Asthenohymen latus, new species

Figure 21

Fore wing. length 7 mm., width 2.2 mm. Costal margin of wing nearly straight, only a slight bulge above origin of CuP, posterior margin strongly curved for its whole length, apex rounded, but the very tip pointed, wing broadest just beyond middle, R1 strongly curved away from margin at pterostigma, pterostigma strongly pigmented in holotype, Cu2 extremely short, the cross-vein connecting it to 1A being closer to the base of CuA than in other species Hind wing similar to the fore wing, but with slightly more rounded anal margin; the specimen identified as a hind wing has a length of 7 mm and width, 2 5 mm

Holotype no 4720, Museum of Comparative Zoology, collected in Midco insect beds (loc. 15-L),

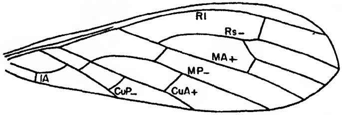

FIGURE 20. *Asthenohymen parvulus*, n. sp. Drawing of fore wing (holotype). Lettering as in figure 1.

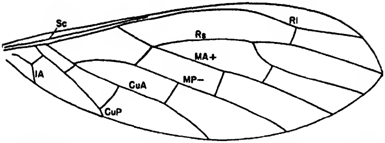

FIGURE 21. *Asthenohymen latus*, n sp. Drawing of fore wing (holotype) Lettering as in figure 1

Noble Co, Oklahoma (F. M Carpenter and G O Raasch). This is a very well preserved and complete fore wing. Paratypes: no. 4702 (loc 15-L), a complete fore wing: no. 4782 (loc. 8-M), a complete hind wing

This species resembles *apicalis* in having the strongly curved posterior margin, but the extreme width of the wing is unique, as is also the basal part of the cross-vein between 1A and 2A.

Asthenohymen dunbari Till.

Asthenohymen dunbari Tillyard, 1924, Amer Jour Sci. **8**: 117; Carpenter, 1939, Proc. Amer Acad Arts Sci. **73**: 31.

In the Midco collection there are about forty well preserved specimens which appear to be identical with *dunbari*, originally found in the Elmo limestone. All of these specimens consist of isolated wings and it is of course possible that the Oklahoma specimens differed from those in the Elmo limestone in body structure (e. g. genitalia); but until evidence to the contrary has been found, I consider them to be *dunbari*.

Asthenohymen pusillus Till.

Asthenohymen pusillus Tillyard, 1926, Amer. Jour. Sci. **11**: 68; Carpenter, 1933, Proc. Amer. Acad. Arts Sci. **68**: 429.

Seven specimens of this insect are present in the Oklahoma collection. As I have pointed out in the case of *dunbari*, we have no way of knowing whether or not the body structure differed from that of the Kansas material It is interesting to note that *pusillus* is rarer than *dunbari* in both the Elmo and Midco beds.

THE VENATION AND RELATIONSHIPS OF THE MEGASECOPTERA

The term "Megasecopterida" was first used by Brongniart (1885) for a "family" of several genera from the Carboniferous of France and England. This group he originally (1885) placed in his Order Pseudo-Neuroptera, together with the Protodonata and Protephemerina; but later (1894) he assigned it to the "Neuropteroid series" of the Order Palaeodictyoptera Handlirsch subsequently (1906) elevated the Megasecopterida to an order, changing the name to Megasecoptera Additional Carboniferous genera, including four from North American deposits, have been referred to the order by Scudder, Handlirsch, Meunier, and Carpenter. The first Permian Megasecoptera (*Protohymen*, *Permohymen* and *Asthenohymen*) were found in Kansas and described by Tillyard (1926) in a new order, Protohymenoptera, considered by him ancestral to the Hymenoptera Other representatives of this group, subsequently collected in the Kansan and Russian Permian, furnished evidence that the Protohymenoptera were really closely related to the Megasecoptera and could be considered a suborder within it. During the past twenty years sixteen more genera of Permian Megasecoptera have been described, some being obviously allied to the Protohymenoptera, and others to the Carboniferous or Eumegasecopterous families. It has now become apparent that the Order Megasecoptera, instead of being primarily a Carboniferous order, did not attain its maximum development until the Permian Period. The interrelationships of these Permian and Carboniferous genera have not been at all clear, and the whole picture of the order has been most confused; but some of the recently discovered fossils, including those described above, have indicated what appears to be the general pattern of evolution within the order, and, at the same time, have raised broader questions of the relationships between the Megasecoptera and other orders.

When, in 1926, Tillyard described the so-called Protohymenoptera from the Kansan Permian, he noted that although the Protohymenidae (*Protohymen* and *Permohymen*) were always preserved with their wings outspread, i. e., in the usual palaeopterous condition, the Asthenohymenidae were preserved with their wings folded over the abdomen, i. e. in the usual neopterous condition. He later

(1936) elaborated on the significance of this difference, and concluded that, "It must now be evident that a group of insects, the Order Megasecoptera, which began as Palaeoptera, have within the limits of a single small derived group, the Protohymenoptera, evolved into a highly specialized Neopterous type, the family Asthenohymenidae! I do not suppose that anybody will attempt to claim that *Asthenohymen* should be separated from its obvious relatives, *Protohymen* and *Permohymen*, which rested with their wings outspread, in order to preserve the two subdivisions Palaeoptera and Neoptera, which are now seen to cut across the actual phylogeny of these ancient groups. The only logical course is to suppress the two groups Palaeoptera and Neoptera, and adopt a classification more in keeping with the facts.

"Surely it must have been obvious for a long time that all Neoptera have been derived from extinct Palaeopterous types. Now the fossil record shows us a group, Protohymenoptera, of either ordinal or subordinal rank, whichever you prefer, in which the change is seen actually taking place . . . My conclusion is that the Order Protohymenoptera shows affinities with both the Megasecoptera and Hymenoptera. It should be regarded as a specialized offshoot from the common ancestor of the Megasecoptera and the Odonatoid complex . . . and, at the same time, as a remnant of the group from which the Hymenoptera have been evolved"

I have quoted these two paragraphs because they were Tillyard's last statements relative to the Protohymenoptera and because of their broad phylogenetic implications. If I understand these remarks correctly, Tillyard contends (1) that the neopterous condition is of polyphyletic origin, and (2) that the Hymenoptera are derived, through the Protohymenoptera, from the common ancestors of the Megasecoptera and the odonatoid complex It is to be noted that no mention is made of the Neuroptera, Mecoptera, and other holometabolous insects which are usually regarded as close relatives of the Hymenoptera However, in 1932 (p 23) Tillyard remarked that if the Protohymenoptera should turn out to be "descended from Megasecoptera, then we may also have to reconsider Handlirsch's view that the Neuroptera are similarly derived."

Since the above articles were written, several fossils have been found which indicate that the origin of the neopterous condition in the Protohymenoptera is not so simple as Tillyard supposed. Tillyard himself subsequently described (1937) another Megasecopteron (*Elmoa*) from the Kansas Permian, representing a new family and in his opinion a remnant of a very old megasecopterous group. This insect subsequently turned out (Carpenter, 1943) to have the neopterous wing condition, like *Asthenohymen*. Furthermore, certain Carboniferous genera are now known to share the same characteristic—two American genera of the family Prochoropteridae (Carpenter, 1943) and the genus *Diaphanoptera*, from France (Brongniart, 1885). Other related families, as the Martynoviidae, were almost certainly similarly neopterous, although, since no complete specimens have been found, we have only indirect evidence of it

Such a series of forms at once suggests that the ability to fold the wings over the abdomen, instead of being developed independently by the Permian Asthenohymenidae, arose in a more ancient and generalized stock This conviction is strengthened by the obviously close relationship between the groups mentioned A comparison of the wings of the Elmoidae, Martynoviidae and Asthenohymenidae reveals several striking characteristics common to all The most obvious of these is the proximal convergence of the strongly convex CuA and R, forming an angle bisected by the stem of M; another is the relative remoteness of R1 and Sc from the costal margin, as contrasted with the position of these veins in the Protohymenidae I have shown above, under the account of the Asthenohymenidae, that the venation of this family can best be explained by comparison with that of the Martynoviids, not with that of the Protohymenids. It is therefore my conviction, on the basis of the evidence now at hand, that the families mentioned (Diaphanopteridae, Prochoropteridae, Elmoidae, Martynoviidae, Asthenohymenidae) form a single phylogenetic line, all having the ability to fold their wings over the abdomen when at rest;[6] and that the other families, such as the Carboniferous Aspidothoracidae, Corydaloididae, Mischopteridae and the Permian Protohymenidae, belong to another phylogenetic line, all holding the wings outspread at rest. This concept separates the family Asthenohymenidae from the Protohymenidae, and indicates that both of these families are highly specialized members of widely divergent lines. The only other alternative is to assume that the Asthenohymenidae have independently developed the neopterous wing folding, the convergent R and CuA, and the other characteristics common to the Elmoid group. Such an assumption seems most unlikely, at best.

[6] It is of course possible that some other described families, represented only by fragmentary specimens, are members of this series.

We are now confronted by even broader questions than were proposed by Tillyard. First, can these two divergent lines be considered members of the one order, Megasecoptera? Second, is the asthenohymenid line derived from the neopterous stock which produced all other neopterous insects, or does it represent an independent development of folded wings? At present we do not have nearly enough evidence to enable us to answer these questions, but there are certain points which can be brought out at this time Although the nature of the wing venation and articulation suggests that the Asthenohymenidae and Protohymenidae are not so closely related as Tillyard supposed, both families, and the lines they represent, do possess certain characteristics in common. The wing membrane was smooth and glassy, and the fore and hind wings were nearly homonomous Both the Asthenohymenidae and Protohymenidae, as well as all other Megasecoptera in which such structural details are known, had very long and multisegmented cerci. The inclusion of the asthenohymenid and protohymenid lines within one order has, therefore, some evidence to support it, in spite of other evidence against it.

The answer to the first question will largely be determined by the answer to the second. If it can be shown that the ability to fold the wings over the abdomen was independently developed in the asthenohymenid line, then presumably there could be no objection to including both lines in the one order On the other hand, if it can be shown that all or any other orders of neopterous insects have been derived from the asthenohymenid line, the two lines should probably be separated into different orders The latter possibility has several interesting and significant implications. Tillyard has expressed the conviction (1926) that the Hymenoptera have been descended from his Order Protohymenoptera and specifically from the protohymenid, rather than the asthenohymenid stock. This clearly means an independent development of the neopterous condition in the Hymenoptera and the Asthenohymenidae, for the protohymenid line was obviously palaeopterous Tillyard has also suggested that the Neuroptera (and presumably all panorpoid orders) were derived from the Megasecoptera (1932), but he does not indicate whether he had reference to the Protohymenidae or some other group of Megasecoptera This recalls Handlirsch's proposal that the Mecoptera, Trichoptera, Diptera, and Lepidoptera are descended from the Megasecoptera, though he concluded also that the Neuroptera and Megaloptera were independently evolved from the Palaeodictyoptera, and he postulated a polyphyletic origin of complete metamorphosis. The latest and most radical suggestion is by Forbes (1943), who contends that all the Megasecoptera, including Protohymenidae, had complete metamorphosis and that the genus *Diaphanoptera* was really a primitive genus of Neuroptera.

I have discussed these phylogenetic questions to show the full significance of some of the suggestions which have been made regarding the relationships of the Megasecoptera. In my opinion, far too little evidence is available to enable us to come to any conclusions on these issues Furthermore, I consider it futile to make taxonomic changes, such as transferring the genus *Diaphanoptera* to the Neuroptera, until the evidence is more nearly conclusive. It is, of course, highly profitable to consider the possible phylogenetic position and significance of fossil and Recent forms, but to change the systematic position of the genera and families according to the latest piece of evidence serves only to increase confusion.

I do propose, however, a modification of the use of the terms "Protohymenoptera" and "Eumegasecoptera." The former was originally employed by Tillyard as an ordinal name to include the Protohymenidae and Asthenohymenidae; but in more recent years it has been used to include all the Megasecoptera-like forms from Permian strata. "Eumegasecoptera" has been employed as a subordinal name for all Carboniferous Megasecoptera. The separation of the families Asthenohymenidae and Protohymenidae into distinct phylogenetic lines, as suggested above, requires a slight change in the concept of the term Protohymenoptera. Since Tillyard specifically stated that the Protohymenidae were the typical members of the Protohymenoptera, they should presumably be included under the latter; and I propose to place also under the Suborder Protohymenoptera the other families of the protohymenid line mentioned above, i. e., the Aspidothoracidae, Corydaloididae, and Mischopteridae Similarly, I propose that the members of the Asthenohymenid line (Diaphanopteridae, Prochoropteridae, Elmoidae, Martynovidae, and Asthenohymenidae) be placed in the Suborder Eumegasecoptera. The position of other megasecopterous families, both Carboniferous and Permian, will not be clear until more of their structure is known.

Order PROTODONATA

Seventeen specimens of three species of Protodonata are included in the Midco Collection. These figures indicate that members of the order are relatively less common in the Midco than in the Elmo beds, which has yielded thirty-six specimens of six

species However, the larger size of the entire collection from Elmo is at least partially responsible for the discrepancy in the figures.

The three protodonates from the Midco beds belong to the family Meganeuridae, each to a different subfamily. All the Elmo species are likewise Meganeurids,[7] but whereas most of the specimens from Midco are Meganeurinnes, the majority of those from Elmo are Typines.

Family MEGANEURIDAE

Subfamily MEGANEURINAE

Genus *Meganeuropsis* Carp.

Meganeuropsis Carpenter, 1939, Proc Amer. Acad. Arts Sci **73**: 39.

This genus was established for a single species (*permiana*) from the Lower Permian of Kansas (Elmo). The species was represented only by two wing fragments of different individuals, but enough was preserved to indicate that the insect was allied to *Meganeura* and that it was at least as large as the Carboniferous *M. monyi* Brong, from France. In the Midco collection there are thirteen specimens of *Meganeuropsis*, all apparently belonging to one species, described below as *americana*. These additional specimens enable us to form a more satisfactory conception of the genus than previously. In the fore wing, the precostal space is long and tapering, extending beyond the middle of the wing, as in all Meganeuridae Sc continues very nearly, if not entirely, to the apex of the wing The stems of R and M are partially fused, forming a double vein, as in other Meganeuridae Rs arises nearly at the separation of R and MA, at a point slightly along MA. R4 + 5 originates about one-fourth the wing length from the base At the origin of R2 there is a distinct oblique vein, as in the Typinae One or two cross-veins between 1A and CuP near the base of the wing are slightly oblique, as in *Meganeura* The area between 1A and the posterior margin is like that of *Meganeura* though the coriaceous area at the very base is not so extensive The hind wing is unknown, except for a very small piece at the base, showing a strongly curved CuP, as in *Megatypus*.

Meganeuropsis differs from *Meganeura* in having a narrower precostal area basally and a smaller coriaceous area at the base of the anal region Other differences will probably be apparent when the complete fore wing of *Meganeura* is known. The oblique vein at the origin of R2 has not been seen in any species of *Meganeura*.

The two known species of *Meganeuropsis* were very large; the new Midco species was about the size of *Meganeura monyi* Brongn. (Commentry, France) while the genotype (*permiana*) was even larger. There is no doubt that *Meganeuropsis* is closer to *Meganeura* than to *Megatypus* and its relatives; but the differences between the Meganeurinae and Typinae are not so great as has been thought. Tillyard (1924, 1925) separated the two subfamilies on the position of origin of R4 + 5 (R3, Tillyard's notation), but the origin of this vein is actually identical in *Meganeura* and *Megatypus* (Carpenter, 1943). The only obvious difference between the two subfamilies is in the length of the precostal area.

Meganeuropsis americana, n sp.

Figures 22, 23, plate 1, figure 2

Fore wing. length, as preserved, 280 mm, estimated entire length, 305 mm Maximum width, 50 mm The wing is slender, especially basally. Details of venation are shown in figure 22. Specific characteristics are difficult to select, but probably in this category are the point of origin of R2 + 3 (just proximal of first posterior veinlet of MA), the position of the origin of R2, and the general nature of all branches

Holotype: No. 4805ab, Museum of Comparative Zoology (loc 15-L), a very well preserved fore wing, 260 mm. long and 50 mm. wide; it lacks only the apex and a piece along the posterior border. Paratypes· No 4812ab (loc. 12-M), consisting of a distal piece of a fore wing, from the origin of R2 + 3 to the apex, 115 mm. long. No. 4806ab (loc. 15-L), a piece of the middle of a fore wing, 95 mm long and 35 mm. wide No 4807ab (loc 15-L), an apical part of a fore wing, 105 mm long and 45 mm. wide In addition there are eleven fragments (not designated types), nos 4808–4811, 4813–4818, from localities 15-L, 8-M, 12-M. Only one appears to be a hind wing; it consists of a piece of a wing base from Sc to 1A, 45 mm long with CuP very strongly arched as in the hind wings of other Meganeurids All specimens were collected in the Midco insect beds, Noble County, Oklahoma, by F. M. Carpenter and G. O. Raasch.

This species is undoubtedly closely related to the genotype (*permiana*), which is, however, known only from two fragments, one being the proximal part of a hind wing. Since the cells are larger and the veins thicker in the fragments of *permiana* than they are in *americana*, the former was probably the larger

[7] The family Calvertiellidae, known only from Elmo, is now placed in the Palaeodictyoptera. See Carpenter, 1943, pp. 536, 548.

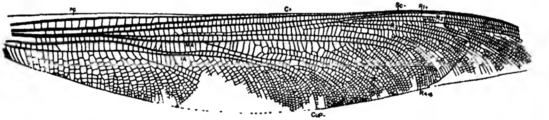

FIGURE 22. *Meganeuropsis americana*, n sp. Drawing of fore wing, based on holotype and paratypes 4812, 4807. R2, R3 and R4+5, branches of Rs, pc, precostal space, other lettering as in figure 1.

insect. More specimens of *permania* may indicate that *americana* is identical with it, but until that is certain, I believe the two should be considered distinct

The holotype wing of *americana*, which is 260 mm long, is, so far as I am aware, the largest continuous specimen of a wing known All specimens of *Meganeura monyi*, which had about the same wing expanse as *americana*, consist of smaller fragments. Two of the paratype specimens of *americana* (nos 4812, 4807) show about 40 mm. more of the distal part of the wing than is preserved in the holotype; since the overlapping areas of these two fossils and of the holotype agree remarkably well, I have added the distal part of these paratypes to the holotype in the drawing of *americana*, figure 22 This brings the length of the part of the wing actually preserved to 300 mm , which is about 5 mm less than the estimated length of the complete wing

There are three aspects of *americana* which deserve further comment One of these is the presence of an oblique vein above the point of separation of R2 and R3. This is obviously the homologue of the vein *Sn* which Sellards described in *Typus permianus* and which also occurs in *Megatypus schucherti* (Carpenter, 1939) We do not yet know that such a vein existed in *Meganeura*, since the area concerned is not well preserved in any specimen, but I presume it did. The phylogenetic significance of this vein is not clear, though it is probably homologous with *Sn* of the Odonata

Another interesting feature of the venation is the thickening of Sc near the point of contact with R1 (Figure 23B). Although only 10 mm. long, it is nevertheless distinct and appears to be an incipient pterostigma, not unlike that of some Megasecoptera (e g. Protohymenoptera) No such structure has previously been observed in the Protodonata

The third noteworthy feature is the presence of plate-like thickenings on the membrane of the wing near the middle of several cells Their distribution over the wing is indicated in the drawing (Figure 22). Eighteen are clearly discernible in the holotype, and others, not distinct enough for recognition, may also be present In one of the paratypes (no 4806) there are a few more platelets than in the holotype, although their general arrangement is the same, and in specimen no 4817, which is part of a hind wing, there are two between 1A and CuP near the base Under high magnification they appear to consist of a minute central disc within a larger, less thickened one, about 5 mm in diameter Identical structures have been described by Bolton on the wings of the meganeurid *Boltonites radstockensis* (Bolton) from the British Coal Measures, and a few are discernible in the published photograph of this insect (1914, pl.

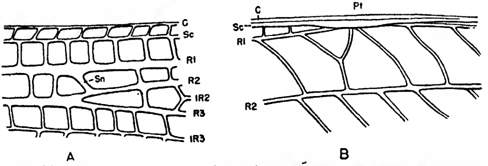

FIGURE 23. *Meganeuropsis americana*, n. sp. A. Drawing of venation in the region of separation of R2 and R3 (holotype). IR2, IR3, intercalary veins; for explanation of Sn, see text. B. Drawing of venation near end of Sc (holotype). Pt, incipient "pterostigma".

18, fig. 1). Reis has described similar markings on the wings of *Reisia gelasii* (Reis), a possible Protodonatan from the Jurassic of Germany. To my knowledge, these are the only recorded occurrences of such platelets on odonatoid wings. However, since noting them in *Meganeuropsis*, I have looked for similar structures, under relatively high power, on Protodonate wings from the Elmo beds, in Kansas. They are very distinct in the specimen of *Megatypus schucherti* which I figured in 1943 (Plate 1, fig 1)—17 between 1A and CuP and a few others in the anal area. None are discernible in specimens of *Typus* or *Oligotypus*. The precise nature of these structures is not at all clear They may be setal bases, though in that case we should expect to find at least a few of the setae preserved [8] Handlirsch has compared those of *Reisia* with similar structures in the Protorthopterous genus *Carcugus* (1911). The latter, however, seem more like the nygmata of various Recent holometabolous insects (see Navas, 1917, Forbes, 1924, Brues, 1933).

Subfamily TYPINAE

Genus *Typus* Sell.

This genus is represented by two species from the Elmo beds in Kansas, and two from the Permian of Arizona In the Midco collection there is another very distinct species.

Typus gracilis, n sp

Figure 24, plate 1, figure 1.

Fore wing length, 145 mm ; greatest width, 26 mm.; slender. Costal margin straight, apex narrowly rounded, posterior margin with maximum width at level of first fork of MA. The distal half of the posterior margin has a slight arcuate curvature Only part of the precostal area is preserved; it is similar to that of *permianus*. Sc approaches close to the costal margin at about the level of the origin of R3, but it remains independent of the costa until near the apex of the wing; R1, Rs, and MA arise as in all Typinae; first fork of Rs as in *permianus*, although R2 + 3 and R4 + 5 diverge more gradually, R2 and R3 separate at about two-thirds the wing length from the base; oblique vein (Sn) present as in other Typinae. R2 diverges away from R1 a short distance before the apex of the wing, and IR2 similarly diverges away from R2. Branches of MA more extensive than in *permianus*. The "vestigial CuA" is present as in *permianus*, except that it appears to fork basally. Two slightly oblique cross-veins are present between 1A and CuP near the wing base. Distance between the base of 1A and posterior margin somewhat greater than in *permianus*, and the veins traversing this area are not joined by cross-veins. The cross-veins in the wing as a whole are about as numerous as those in *permianus*, much fewer than in *readi*. Hind wing unknown.

Holotype· no 4818, Museum of Comparative Zoology, collected in Midco insect beds (loc. 12-M), Noble Co., Oklahoma, by G. O Raasch. This specimen consists of a complete and well preserved fore wing (plate 1), and is one of the most striking fossils in the Midco collection.

This species presumably had a wing expanse of about 300 mm., nearly one and a half times that of *permianus* It also differs from *permianus* in having a more slender wing and straighter veinlets between 1A and the posterior margin proximally It differs from *T readi* in wing shape and especially in having fewer cross-veins (Carpenter, 1939, fig 7).

One of the most interesting features of this wing is the structure of the "vestigial CuA" at the base of the wing This vein apparently occurs in all Typinae (and even in Meganeurinae, see Carpenter, 1943, fig. 2), but it is more clearly preserved here than in other specimens of the group which I have seen. It is composed of two thin veins, one just below M and abruptly curved posteriorly, and the other near the base of CuP and straight Since both MP and CuA are missing in the Typinae (as well as Meganeurinae), it may well be that the anterior element is a vestige of MP and the posterior one a vestige of CuA At present, however, there is no Protodonatan known in which these veins are intermediate between the fully developed and vestigial conditions.

Oligotypinae, new subfamily

This subfamily is established for the genus *Oligotypus*, previously known by the genotype specimen from the Elmo beds, and placed in the subfamily Typinae. A new specimen of this insect in the Midco collection provides further information which convinces me that the genus should be separated from *Typus* and *Megatypus* at least by subfamily rank. The characteristics of *Oligotypus* for which the subfamily is formed are as follows: in the fore wing, R2 + 3 and R4 + 5 are widely divergent; Sc terminates slightly beyond mid-wing; MA lacks true branches, so that the area occupied by MA distally

[8] Dr. W. T. M. Forbes has called my attention to the occurrence of setae on the wing pads of certain odonate nymphs. It is conceivable that in the Protodonata setal bases might have been carried over from the nymphs to the adults.

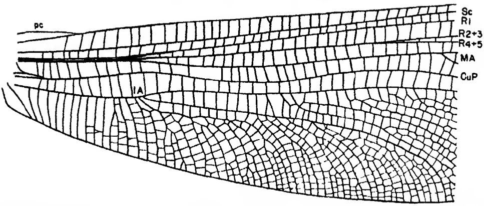

FIGURE 24 *Typus gracilis*, n. sp. Drawing of proximal half of fore wing (holotype). Lettering as in figures 1 and 22.

is very small. The so-called vestigial CuA is completely absent, as is also the oblique vein at separation of R2 and R3. The other two subfamilies of the Meganeuridae (i. e. Meganeurinae and Typinae) are alike in having closely approximate branches of Rs, a longer Sc, a multi-branched MA, and a strong oblique vein at the separation of R2 + R3 *Oligotypus* obviously differs from the Meganeurinae and Typinae more than the latter do from each other The hind wing of *Oligotypus* is still unknown

Genus *Oligotypus* Carp

Oligotypus tillyardi Carp.

Figure 25

Oligotypus tillyardi Carpenter, 1931, Amer. Journ Sci **21**: 106.

The specimen (no 4804ab, loc. 15-L) in the Midco collection is a fore wing, and, though lacking the distal quarter, is much better preserved in other respects than the holotype. It is the same size as the holotype (40 mm. long, as preserved, 11 mm. wide) and has a very similar venation; but it includes the proximal part of the wing, which, although I was not aware of it, was absent in the type. The base of the wing is now seen to be essentially like that of other Meganeurids. The precostal area is small, as in *Typus*, and the wing is decidedly narrow across the base The most interesting aspect of this part of the wing is the total absence of the so-called vestigial CuA, which is apparently present in all other genera of Meganeuridae. The proximal part of the wing is so very well preserved that I am convinced that its absence is not merely due to lack of preservation.

It should be noted that there is no sign in the new specimen of the "obsolescent MP," which I mentioned and figured in my account of the type of *tillyardi*. Further examination of the type convinces me that the short vein indicated in my drawing (1931, p. 107, fig. 2) is really the stem of M, broken away (by pressure) from the stem of R, with which it is normally contiguous.

Order ODONATA

Suborder PROTOZYGOPTERA

Family KENNEDYIDAE

This family is represented in the Midco collection

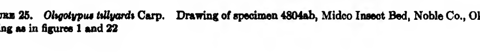

FIGURE 25. *Oligotypus tillyardi* Carp. Drawing of specimen 4804ab, Midco Insect Bed, Noble Co., Oklahoma. Lettering as in figures 1 and 22

by fifteen specimens, four more than have been secured in the Elmo beds (Kansas). The new fossils belong to the Elmo genera *Progoneura* and *Kennedya*, but include three new species, two of which greatly extend our knowledge of *Progoneura* The family Kennedyidae has so far been found only in the Wellington formation The obscure genus *Sushkinia* from the Russian Permian, though originally assigned to this family by Martynov (1930), has subsequently been placed in the family Permolestidae (Martynov, 1937).

Genus *Kennedya* Till.

Kennedya Tillyard, 1925, Amer Journ Sci. **10:** 63. Carpenter, 1939, Proc Amer Acad Arts Sci **73:** 45

This genus has previously been known by three species from the Elmo beds· *mirabilis* Till, *tillyardi* Carp. and *reducta* Carp, though the last will probably turn out to belong to another genus In the Midco collection there is one new species, as well as *mirabilis*. The wings of *Kennedya* are decidedly petiolate and have a distinct nodal bend on the anterior margin, 1A is long, extending well beyond the level of the nodus. Fraser has pointed out (1939) that in this genus the antenodals are aligned with the subcostal cross-veins below, though this is not always strictly the case, as shown by my figures of *mirabilis* and *tillyardi* (1939, p 46) and in the figures included here It is true, however, that they are more nearly aligned in *Kennedya* than in *Progoneura*

In the present collection there are nine specimens of *Kennedya*, of which five are too incomplete for specific determination

Kennedya fraseri, n sp

Figure 26

Wing: length, 40 mm , width, 5 8 mm. (holotype), shape much as in *mirabilis*, only three postnodals, pterostigma slightly longer than that of *mirabilis*, 1A close to posterior margin; cross-veins much more numerous distally than in either *mirabilis* or *tillyardi*, forming a distinct reticulation, four cross-veins between R2 and 1R2; five between R3 and 1R2; six between R3 and 1R3; nine between R3 and R4 + 5. Venation similar to that of *mirabilis* in other respects.

Holotype· no. 4793, Museum of Comparative Zoology; collected in Midco insect beds (loc. 3-M), Noble Co., Oklahoma (F. M Carpenter and G. O. Raasch). This specimen consists of a complete and well preserved wing. It is probably a fore wing.

Paratypes· no. 4790ab, Museum of Comparative Zoology; same collecting data as holotype, but locality 16 This well preserved wing is 34 mm long and 5 8 mm wide, it is a little shorter and relatively broader than the holotype and is therefore almost certainly a hind wing. No. 4821ab, also from locality 16; a nearly complete wing, lacking about 4 mm of the apex. It has the same dimensions as the previous specimen

This species is named for Dr. F. C. Fraser, who has greatly advanced our knowledge of Odonate evolution. It differs from the previously described species of *Kennedya* mainly by having more cells in the distal part of the wing. Of particular interest is the presence of four cross-veins between R2 and 1R2; in *mirabilis* there are no cross-veins at all in this area, and in *tillyardi* (so far as known) there is only one The large number of cells in *fraseri* carries a suggestion of the condition in Permolestidae

Kennedya mirabilis Till.

Kennedya mirabilis Tillyard, 1925, Amer. Journ Sci **10:** 66, Carpenter, 1939, Proc Amer Acad. Arts Sci **73:** 45

Two specimens apparently belonging to this species are in the Midco collection (no. 4795, loc 8-M; no 4798, loc. 5). Each consists only of the distal half of a wing, so that determination is not certain.

Genus *Progoneura* Carp.

Progoneura Carpenter, 1931, Amer. Journ. Sci **21:** 120. 1933, Proc Amer Acad Arts Sci **68:** 418. 1939, ibid **73:** 47

This genus has previously been known only by three specimens of one species (*minuta*) from the Wellington formation in Kansas Since all of these

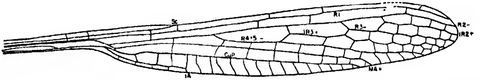

FIGURE 26. *Kennedya fraseri*, n. sp. Drawing of holotype. R2, R3 and R4+5, branches of Rs; IR2 and IR3, intercalary branches of Rs; other lettering as in figure 1.

are fragmentary or poorly preserved, little has been known of the wing venation, except the arculus region and the petiole In the Midco collection there are five specimens of *Progoneura*, all but one being well preserved and nearly complete wings. It is now possible, therefore, to make a satisfactory comparison of its venation with that of *Kennedya*.

The wings as a whole, though shaped like those of *Kennedya*, are not so abruptly petiolate, the proximal half being more tapering. Also, the costal margin is very nearly straight with hardly a discernible break at the nodus. Two or three antenodals are present,[9] not aligned with the subcostal cross-veins below; R1 is very remote from Rs. The stem of the arculus is apparently variable in length, in the genotype it is long but in one of the new species (*venula*) it is very short. CuP + 1A is strongly arched below the stem of arculus, and is more undulated in the petiole than it is in *Kennedya* 1A is very short, ending at least at the level of the nodus Finally, there are only about half as many cross-veins in *Progoneura* as in *Kennedya*, the venation consequently being very open.

In many respects the genus *Progoneura* is more generalized than other known Protozygoptera This is indicated by the absence of a nodal bend at the end of Sc, the deviation of the antenodals and the subcostal cross-veins, the tapered petiole, and the undulated CuP + 1A in the petiole. The short 1A and the very small number of cross-veins may also be in this category.

The following species of *Progoneura* are present in the Midco collection.

Progoneura nobilis, n. sp.

Figure 27

Wing· length, 13 mm.; width, 2 5 mm. (holotype) Costal margin with a very slight nodal bend; pterostigma prominent, light reddish brown (as preserved), and slightly swollen; apex pointed, posterior margin conspicuously curved, stem of arculus long, 1A terminating below the nodus; R4 + 5 arising at a point far distal to level of nodus; cross-veins arranged as in figure 27. The antenodals and "vestigial CuA" are not preserved, the areas including these structures being broken away.

Holotype: No. 4786ab, Museum of Comparative Zoology, collected in Midco insect beds (loc. 16), Noble Co., Oklahoma (F. M Carpenter and G. O. Raasch) It consists of a complete and well preserved wing.

Paratype: no 4788ab, Museum of Comparative Zoology, collecting data as for holotype, except for the locality, which is 15-L. This is a nearly complete wing, 15 mm. long and 2.8 mm. wide, lacking only a small piece at the end of MP and at the origin of 1R2. The antenodals are not preserved. The wing is slightly broader at the level of the arculus than it is in the holotype, but the venation is very nearly identical with that of the latter In all probability the holotype is a fore wing and the paratype a hind wing.

This species is similar in venation to the genotype (*minuta*) but differs in having a much longer arculus stem and in having 1A terminate at about the level of the nodus. Other differences probably exist but further comparison cannot be made because of our incomplete knowledge of *minuta*.

Progoneura venula, n. sp.

Figure 28

Wing. length (as preserved), 16 mm ; width, 2.8 mm , estimated whole length, 17 5 mm. Costal margin without a discernible nodal bend, pterostigma prominent, somewhat longer than that of *nobilis*; apex pointed; posterior margin not so strongly curved as in the latter; stem of arculus very short, much like that in *Kennedya*, 1A terminating far proximal to the level of the nodus, two antenodals present; the more distal antenodal occurring in *minuta* is not visible in *venula*, possibly because the membrane is partially broken away at the corresponding region. Cross-veins arranged as shown in figure 28.

Holotype: No. 4791, Museum of Comparative Zoology; collected in Midco insect beds (loc. 16-M),

[9] The holotype of *Progoneura minuta* (genotype) has a third antenodal between C and Sc just above the arculus, but there is no indication of this in other specimens.

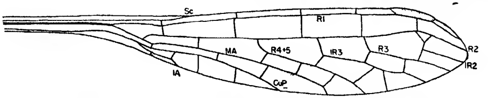

FIGURE 27. *Progoneura nobilis*, n. sp. Drawing of holotype. Lettering as in figures 1 and 26.

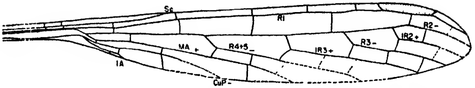

FIGURE 28. *Progoneura venula*, n. sp. Drawing of holotype. Lettering as in figures 1 and 26.

Noble Co., Oklahoma (F. M. Carpenter and G. O. Raasch). The specimen consists of a nearly complete and well preserved wing, lacking the very base of the petiole and a small piece along the posterior margin.

This wing differs from those of *nobilis* and *minuta* in having a very short arculus stem, with the corresponding shift in the position of A1, and in having the origin of R4 + 5 more proximal.

Progoneura sp.

In addition to the above, the Midco collection contains one specimen (no. 4792, loc. 8-M), which apparently represents a third species. It consists of the proximal half of a wing, 17 mm. long, indicating that the whole wing was about 34 mm, fully twice the size of other species of the genus. The preserved part of the wing is characteristic of *Progoneura*, but since the nodus and the distal piece of Sc are not known, I believe the species should not be described until more specimens have been found

Suborder PROTANISOPTERA

Family DITAXINEURIDAE

Ditaxineura cellulosa Carp

Ditaxineura cellulosa Carpenter, 1933, Proc Amer Acad Arts Sci. **68**: 419.

This species is represented in the Midco collection by the distal fragment of a wing (no. 4801ab, loc. 8-M), 14 mm. long Its size, venation and pterostigma agree fully with those of *cellulosa*, described from the Elmo beds. The convexities and concavities are very well preserved and show that the posterior "branch" of MA depicted in my figure of *cellulosa* (1933) is really a concave, intercalated sector, as in *anamalostigma*. In the type of *cellulosa* the concavity of the vein was obscured by irregularities.

A second wing fragment (no. 4802ab, loc. 15-L) also belongs to *Ditaxineura*, probably to *cellulosa*, but it consists of the proximal half of the wing only, and is poorly preserved, so that its specific identity is uncertain.

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Explanation of Plates

Plate 1

Figure 1 *Typus gracilis*, n. sp. Photograph of holotype (4818). × 1.3
Figure 2 *Meganeuropsis americana*, n. sp. Photograph of holotype (4805). × 65

Plate 2

Figure 1 *Eumartynovia raaschi*, n. sp. Photograph of holotype (4822). × 8.5
Figure 2. *Parelmoa revelata*, n. sp. Photograph of holotype (4680) × 12

PLATE I

1

2

PLATE 2

1

2

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THE COMPRESSION OF 39 SUBSTANCES TO 100,000 KG/CM²

By P W Bridgman

ROUGH COMPRESSIONS OF 177 SUBSTANCES TO 40,000 KG/CM²

By P W Bridgman

Investigations on Light and Heat made and published with aid from the Rumford Fund

THE COMPRESSION OF 39 SUBSTANCES TO 100,000 KG/CM²

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Harvard University, Cambridge, Massachusetts

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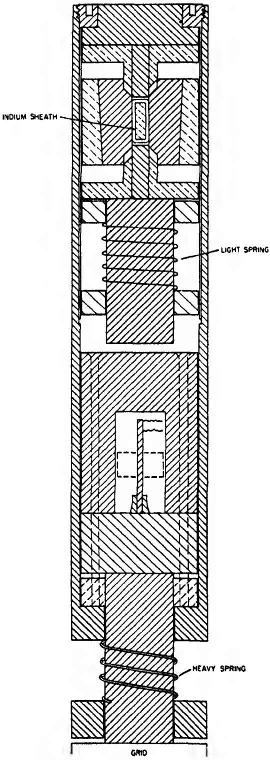
Introduction

In this paper the program of measurement of the compressions of various substances to 100,000 kg/cm² already initiated in two papers (1) is continued to 39 substances, including elements, various sulfides, selenides and tellurides, and 6 glasses A number of improvements have been made in the apparatus, permitting somewhat greater accuracy and consequently the extension of the measurements to substances with too low a compressibility to have been previously attempted.

Apparatus and Method

The apparatus consists essentially of a miniature high pressure piezometer entirely surrounded by an outer pressure vessel containing fluid in which the pressure may be raised to 30,000 kg/cm² in order to support the miniature piezometer Measurements are made of the force driving the pistons of the high pressure piezometer and the displacement of those pistons Previously the force has been measured in terms of the change of electrical resistance of a compression member mounted within the pressure vessel by which the force is transmitted to the high pressure pistons, and the displacement by measuring the displacement of the piston of the external pressure vessel, which is transmitted through various intermediate members to the high pressure pistons This latter measurement has always been more or less unsatisfactory because of the distortion of the transmitting members, which are subject to friction and hysteresis in a way not completely reproducible The major improvement in the new apparatus consists in measuring the displacement of the high pressure pistons from the inside of the 30,000 pressure vessel, thus eliminating the irregularities due to friction and hysteresis This has been done by attaching the pistons to a moving slide wire of the same type as that used in much of my previous work. The displacement of the wire is determined in terms of the potentiometer resistance of that portion of the wire included between a terminal fixed to the wire and a contact fixed to the rest of the apparatus over which the wire slides The method demands three electrically insulated leads, two for the potential taps to the potentiometer, and one for the current, the other current terminal being grounded In all, seven electrically insulated leads into the pressure vessel are now needed, three for the "grid" with which the force driving the piston is measured, one for the manganin pressure gauge, and three for the displacement Formerly, it had not been found possible to make insulating pressure plugs which would carry more than four terminals My mechanic, Mr. Charles E. Chase, has now found with great skill how to construct plugs with seven terminals, and this alone has made possible the improvement in the method No essentially new feature is involved



in the new plug, but only the refinements of smaller and more accurate construction. The individual terminals are like those shown in Figure 2. As experience has been gained, it has become possible to dispense with various artifices formerly thought necessary, such as the secondary plastic packing above the cones, and the preliminary application of pressure with a heavy oil. At the same time the life of the insulation has been very much extended; seventy-five applications of 25,000 to 30,000 have been made before it was necessary to renew the insulation, whereas when this work started a single application could not be counted on.

In addition to this major improvement a number of minor improvements were made. The sensitivity of the grid with which the force driving the pistons is measured was doubled by changing the dimensions, making the grid shorter and thinner in section The sensitiveness of the force measurement is now about one part in 200 at the maximum This measurement was the mean of three settings on the potentiometer wire, with different directions of current flow and in a time sequence to eliminate effects due to any drift in the parasitics, and could be counted on to the limit of sensitivity of the individual readings, 0 1 mm. on the slide wire, or perhaps a trifle better The sensitivity of reading of piston displacement was, with the original arrangements, some ten or twenty times as great as this So great sensitivity could not all be used, and therefore opportunity was taken to improve the design of the piezometer and pistons, at the same time cutting down the displacements to one half This was done by giving the piezometer the design shown in Figure 1 and in greater detail in Figure 3. The effective occupied length, that is, the length of the charge, is cut to one half by enlarging the mouth of the piezometer at both ends as shown. The stroke of the piston is correspondingly cut in half, which makes it possible to more effectively support the piston and minimize its plastic flow and lateral expansion The new design of the piezometer decreases the friction of the charge as it slides on the sides of the piezometer by more than a factor of two, friction being exponential in the length, increases the bursting pressure of the piezometer appreciably because of the support afforded by the end regions

FIGURE 1 General view of the assembly, showing how the motion of the pistons of the piezometer (upper part) is transmitted to the measuring wire (lower part).

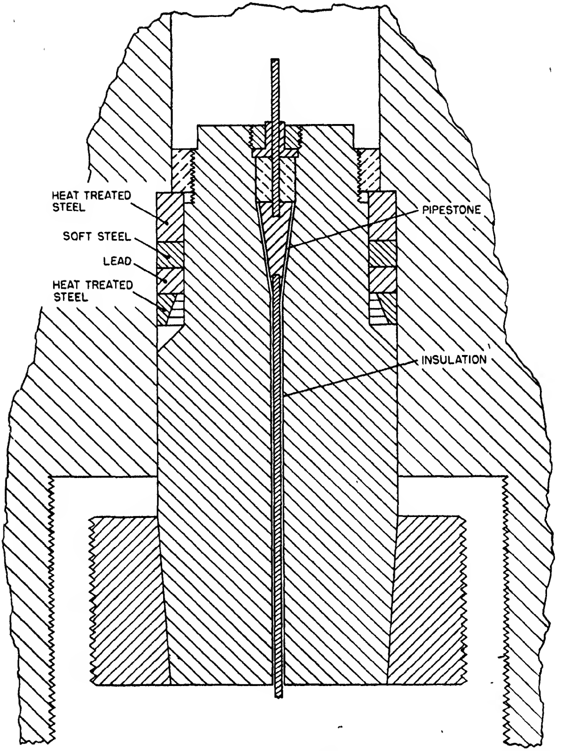


FIGURE 2. Improved design for getting electrical leads into the pressure cylinder, together with the improved split ring packing

which are not exposed to internal pressure, and by the same mechanism decreases the barreling of the interior under internal pressure and so minimizes a small source of error in the computed distortion of the piezometer The piezometers were made of grade 799 carboloy, with shrunk on steel jacket. This grade of carboloy has proved exceedingly well adapted for this purpose, no piezometer made of this grade ever having ruptured in use In my earlier work ruptures of the

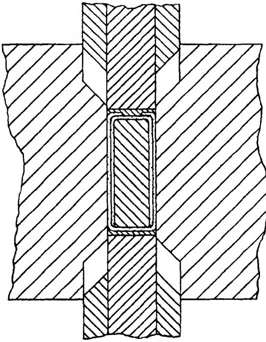


FIGURE 3 Enlarged view of the piezometer, showing method of sealing an alkali metal inside a double capsule of aluminum

piezometer were common, but the piezometers were then made of the less suitable 905 grade In the present work one piezometer has been exposed to 40 and the other to 50 applications of the maximum pressure, which was always at least as high as 100,000 and might infrequently reach nearly 110,000. The plastic flow of the piezometers under these conditions was slight In use there is perceptible plastic enlarging of the interior, but this is very slow During operation it was necessary to refigure only once by enlarging the bore from 0 0620 to 0 0625 inches The pistons, as described previously, were best made of grade carboloy 999. The quality of this grade is not entirely uniform and it is desirable to make preliminary examination to find a batch with a high plastic flow point In use the pistons are made 0 0004 inches smaller than the hole so that at no time will they expand sufficiently to touch the sides of the cylinder and thereby introduce friction. Under these conditions the pistons permanently expand by about 0.0001 inch after every excursion to the maximum, and they have to be refigured after every such use. Eventually after perhaps a dozen or fifteen refigurings the flow limit is reached, minute cracks begin to appear, and the pistons must be replaced. The shrunk on steel support around the unused part of the piston, as shown in Figure 3, materially adds to the life, there is no plastic flow in this part of the piston The clearance of 0 0002 inches between piston and cylinder walls is large enough to put demands on the cup shaped steel packing between the end of the piston and the charge If this is made of a soft steel it will be extruded between piston and wall with consequent friction and also danger of discing off the end face of the piston where it is pinched A packing made of a heat treated steel with a Rockwell C hardness of 40 gave no trouble from this extrusion

Friction between charge and cylinder walls was further materially reduced below that attained by halving the length of the charge by completely encasing the charge in an indium sheath This sheath was formed in place in the cylinder with a suitable forming tool There is, of course, a disadvantage in that the presence of the indium cuts down the amount of working substance and furthermore introduces an additional correction because of its compression. The advantages, however, usually outweighed the disadvantages If the substance is mechanically soft, such as aluminum or magnesium, the sheath may be omitted The volume of the indium in the sheath was usually approximately one half that of the working charge Quantities of indium and charge were determined by weighing in a specially constructed micro-balance good to better than 0 00001 gm , the usual weight of the indium was around 0.016 gm

Two improvements were made in the technique of handling the production of the supporting pressure of 30,000 kg/cm². At one time a long series of capricious irregularities was encountered which was finally traced to freezing of the transmitting liquid, i-pentane This was commercial material from the Eastman Kodak Company. The trouble was finally associated with the use of a new batch of this liquid The explanation is

that Eastman has recently improved their method of preparing this liquid, so that it is now purer than formerly and therefore has a sharper freezing point. The remedy is to mix with the i-pentane half its volume of commercial "pentane" Even this mixture at the maximum pressure capriciously becomes sufficiently viscous to introduce appreciable non-hydrostatic forces, so that a redesign of the method of coupling the pistons to the slide wire measuring their displacement was necessary. Originally the coupling was by push contact for one direction of stroke, but on the reverse stroke a stiff spring was used to maintain contact. The spring was not strong enough always to overcome the stiffness of the liquid, so that the connection had to be redesigned to ensure positive transmission of motion for both directions of stroke The second change in technique was in the packing ring closing the insulating plug at the bottom of the 30,000 apparatus This had never been entirely satisfactory, but would leak slightly after long use in a way not easy to definitely locate It appeared that after prolonged use with consequent work hardening the packing ring becomes loose on the inside surface, while remaining tight at the outside The remedy was to make the packing ring double, an inside part sliding conically in the outer part, as indicated in Figure 2 In virtue of slip on the conical surface the inside as well as the outside now is pressed tightly against the retaining walls Some fifty applications have been made without leak, the apparatus then having been taken down for another reason

The various corrections and calibrations necessary in connection with the slide wire method of measuring displacement were determined by methods sufficiently obvious which have been previously used, so that they need not be described again in detail. It is an advantage of the method that the corrections are all small The pressure coefficient of resistance of the wire was determined by a pressure run with the wire clamped. The validity of the corrections and calibrations was checked by measuring between 25,000 and 30,000 a known displacement of the same magnitude as the piston displacements encountered during the compression measurements This was done by measuring the plastic shortening of a cylinder of copper, the shortening being terminated by a hardened steel stop when it had progressed by a known amount. The driving force is plotted as a function of displacement. There is a discontinuous change in direction when contact is first made with the copper and again when the stop is encountered. Since the cubic compressions of steel and copper are known, all the material is at hand for a calculation of the expected displacement, thus permitting a comparison with that given by the slider. The two measurements differed by 0 0001 inch on a displacement of 0.0350 inch, which is agreement to better than the sensitiveness of the force measurements

The new set-up permits a check of a correction in the measurement of driving force by means of the grid This correction is for the pressure coefficient of the simple compression coefficient of the electrical resistance of the grid. It is the largest of any of the corrections in this work, rising to something over twenty per cent. It had been previously determined from the average of several hundred determinations of the extra

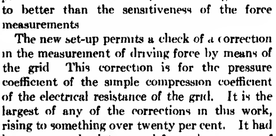


FIGURE 4 The compound tension specimen, with which the correction for the effect of pressure on the compressive constant of the "grid" is determined

force required to drive the main piston of the 30,000 apparatus when it makes up against the grid. There is a rather large component of friction, and there was much scatter in the individual readings, so that an entirely independent confirmation was desirable. The possibility of such confirmation was afforded by the method used for studying the effect of pressure on the tensile strength of brittle substances described in a previous paper (2) The tension specimen is replaced by a double specimen of hardened steel, as indicated in Figure 4. A thin copper sheath unites the two steel pieces. The specimen was mounted in the holder for tensile specimens in the 30,000 apparatus, and, at a pressure of 21,000, the tensile force is measured which is required to separate the two steel specimens by measuring the change of resistance of the grid The thin copper sheath prevents entrance of the transmitting liquid between the ends of the steel pieces, so that the force required to separate the steel pieces is equal to the force exerted by the known hydrostatic pressure over the cross section, plus a

small correction, about 2 per cent, for the breaking strength of the copper. The agreement was perfect between the separating force determined from the hydrostatic pressure and that calculated from the resistance change of the grid using the previously determined pressure correction, thus checking the latter

Having determined the displacements and the force on the piston, the final results are to be computed in exactly the same way as in previous papers, so that this need not be described again In this computation the fiducial volume is that at 25,000 kg/cm². For many of the substances of this paper an independent determination of this has not been previously made, so that new measurements up to 25,000 were desirable These were made in a new apparatus permitting very rapid measurements at room temperature with very small corrections. This apparatus has been previously described (3) and results obtained with it for 61 substances up to 25,000 kg/cm² It has now been found that the same apparatus can be used without modification up to 40,000 instead of 25,000 and measurements have been made with it on some 175 new substances, including those of this paper. For these substances we thus have overlapping measurements by two different methods in the range between 25,000 and 40,000, which affords a desirable check This check, however, is not given under optimum conditions, since the comparison is between the upper end of the range of one instrument and the lower end of the range of the other. In a few cases the fiducial volume at 25,000 was not independently known from other experiments In these cases it is possible to obtain a fairly satisfactory value from the absolute setting of the potentiometer when the high pressure pistons first establish contact with the grid in the neighborhood of 25,000. It is the differential settings of the potentiometer which determine the volume changes above 25,000.

The final results are, as before, strictly differential results between the substance in question and gold, assuming for the latter an extrapolation by Murnaghan's formula Even if the accuracy of the measurements permitted it, which they do not, we are not yet in a position to obtain the absolute compressibility of any single one of the relatively incompressible substances up to 100,000 with any accuracy. The relative compressibilities, however, are determinable within the accuracy of the measurements.

In making the measurements, complete data were recorded for the piston displacement by both the former (external piston) and the new (slide wire) methods. The displacements by both methods were calculated for about half the substances. These definitely established the superiority of the new method, both in smoothness and consistency, while at the same time showing no over-all discrepancy between the two methods, so that there is no reason to fear any consistent error in the results already published In view of this and also of the fact that calculations by the former method are much more time consuming than by the new, only the new data by the slider method were used in the computations for the other half of the substances

As before, most of the substances were independently measured in two different piezometers. There are, however, a few of the more incompressible and unusual elements which have been measured in only one piezometer. Since in any event no high accuracy can be expected for these elements the chief interest of the measurements for them lies in the information obtained with regard to the presence or absence of new polymorphic forms in the new pressure range.

The detailed presentation of results now follows. The order is first the five alkali metals in order of atomic weight, then 17 other elements in order of atomic weight, then ten compounds including the sulfides, selenides and tellurides of zinc, mercury and lead, and quartz crystal, and finally six glasses

Detailed Results

Alkali Metals Results for all of these metals except caesium have already been published. These are of especial theoretical interest because the structure of these elements is sufficiently simple to permit theoretical calculation of the volume changes under pressure Furthermore, they should at first sight be among the easiest to measure experimentally because the compressibilities are among the highest of the elements Unfortunately, however, they turn out to be among the most difficult to determine experimentally, and of all the materials formerly measured the results were least accurate for them. It was therefore thought to be worth while to redetermine them with the present more accurate method. The difficulty arises from the great mechanical softness of these metals and their high chemical activity. It had already been established that the carboloy piezometer is ruptured if pressure is directly transmitted to it by sodium,

and there was evidence that lithium might produce a similar fracture Accordingly the alkali metal has to be enclosed in some sort of a protecting sheath. This sheath should obviously be as soft mechanically as feasible In the previous work a sheath of copper was used, the total volume of the copper being of the order of twice that of the metal and its contribution to the compressibility of the order of one fifth that of the alkali. The friction exerted by so much copper proved to be sufficient to introduce a rather large uncertainty into the final result In attacking the problem again, search was first made for a softer metal out of which to make the protecting sheath Sodium was first tried in a sheath of indium. On application of 100,000 there was a large permanent change of volume, and on release the two metals were found to be completely alloyed Sodium in a sheath of lead was then tried Again there was an irreversible and permanent decrease of volume, much less than before, but too much On cutting open the capsule a region of alloying was found at the surface of contact It was concluded from this experience that alloying would be produced in the cold by these high pressures if the alloy existed The extremely extensive book of M Hansen on binary alloys of the metals was then consulted, and the softest metal known not to alloy with the alkali metals found to be aluminum This is harder than would be desirable, but still much softer than copper The aluminum sheath was made in the form of a double cup, as indicated in Figure 3 A simple technique was worked out by which the filling was accomplished under petroleum ether, the petroleum ether removed by evaporation, still leaving a protecting atmosphere of petroleum ether, the outer cup slipped over the filled inner cup, and the projecting edge of the outer cup swaged over the inner cup while still in the protecting atmosphere, and then the final closure of the cup accomplished by spinning in a jeweler's lathe The atmosphere was thereby effectively excluded, and the capsules were capable of remaining indefinitely in the air of the room with no evidence of chemical action. The quantities were determined by an initial weighing of the aluminum cups and a final weighing of the filled capsule In the case of caesium the room was cooled to about 10° C by opening the windows during the filling, and all pieces of metal in contact with any part of the filling apparatus as well as the petroleum ether were prechilled to 0° C Caesium was not previously measured above 45,000 The reason for this was entirely accidental, the apparatus for 100,000 had been filled and pressure applied up to the maximum when the piezometer broke This was at the end of the previous series of measurements, when war work was pressing to be done, and I was not able at that time to return to it Except for the inconvenience of the low melting point, there is no greater intrinsic difficulty with caesium than with any of the other alkali metals, and the same arrangements will serve

The source of the alkalies, except caesium, was my own stock, with which many of my previous results have been obtained and known to be of adequate purity, kept sealed under Nujol The caesium, however, was obtained from a previously unopened glass capsule sealed in vacuum obtained from Mackay before the war, one of several such capsules, others of which had been used in my previous work The caesium was obviously impure with its own oxide, as shown by its bright yellow color and indefinite freezing It was purified, as in my previous work, by distillation at the minimum temperature in a high vacuum and over an interval of several hours The evidence of purity is the disappearance of the yellow color and sharpness of freezing

The volumes of the five alkalies obtained with the present apparatus are shown as a function of pressure in Table I As already mentioned, the

TABLE I

VOLUME OF THE ALKALI METALS

Pressure kg/cm²	Lithium	Sodium	Potassium	Rubidium	Caesium
1	1 000	1 000	1 000	1 000	1 000
25,000	851	789	691	675	600
40 000	833	770	668	652	571
10,000	801	737	628	612	521*
50,000	773	708	595	578	431
60 000	718	683	568	551	409
70 000	727	661	546	528	392
80 000	707	611	528	507	381
90 000	689	623	513	189	375
100 000	672	606	500	473	368

* Discontinuity of volume of 056 at 45 000

volumes at 25,000 kg/cm² are, those given by measurements in the new apparatus for 40,000 Values of the volumes below 40,000 will be found in a paper following this describing the reults with that apparatus It is debatable how best to present the final results in the pressure range in which there are independent determinations with different pieces of apparatus In some of my early work the course was adopted of adjust-

ing the values given by one apparatus in the direction of those given by the other in the overlapping ranges Such a procedure is obviously to a certain extent arbitrary. The simpler and perhaps safer course is now adopted of reporting the results obtained with the present apparatus for 100,000 without any adjustment at all for the results obtained with the 40,000 or other forms of apparatus The values obtained with the two pieces of apparatus at 40,000 will be stated however This will put the reader in a position, in conjunction with the data of the other paper, to make his own adjustments as he sees fit The same course will be followed with the other materials of this paper The comparison of the results with the two pieces of apparatus is as follows At 40,000 the volume obtained with the 40,000 apparatus for lithium was 0 796 against 0 801 with the present 100,000 apparatus, for sodium 0 726 against 0.737, for potassium 0 633 against 0 628, for rubidium 0 605 against 0 612, and for caesium 0 518 against 0 521 The results with the 40,000 apparatus at 40,000 are somewhat lower than with the present apparatus, which means that the 40,000 apparatus gives a somewhat greater compressibility in the range 25,000 to 40,000 than does the present apparatus

Compared with the previous measurements to 100,000 the new measurements give consistently larger volumes at the top pressure than before The difference is spread over the entire pressure range, but accelerates markedly at the upper end of the range The comparison of the volumes at 100,000 is as follows for lithium 0 672 now against 0 606 before, for sodium 0 606 against 0 560, for potassium 0 500 against 0 427, and for rubidium 0.473 against 0 362 The new results give a more rapid falling off of compressibility at the high end of the range than formerly, which is in the direction which certain theoretical considerations had suggested as probable

By far the most interesting of the new results is the volume discontinuity found for caesium at approximately 45,000, just at the end of the previous measurements The single run previously made with increasing pressure just before the apparatus broke showed the same effect The volume change is comparatively large, about 11 per cent This volume change is in addition to the one already known at about 23,500 kg/cm^2 (5), at which occurs a change from the body centered to presumably the face centered arrangement, according to the calculations of Bardeen (6). The new transition must therefore be from an arrangement which is already close packed to something else; the question is what can it be The new transition is clean cut, reversible, and runs rapidly in either direction with little pressure transgression Above the transition the new modification of caesium has, in comparison with the other alkalies, an unexpectedly small compressibility, which drops off abnormally rapidly with increasing pressure In the table a reversal in the trend of the compressibility to drop with increasing pressure is indicated at the last interval between 90,000 and 100,000 This may or may not be real; the figures were given as they came without final smoothing

Other Elements. In Table II the volumes of 17 other elements are given up to 100,000 In general those elements were chosen which had not already been measured which have a compressibility large enough to be inviting A five per cent change of volume at the maximum pressure is about the minimum that should be attempted—ten per cent is better. In addition to these a number of elements were tried whose position in the periodic table suggested them as candidates for polymorphic transitions

Detailed comment on the elements of Table II now follows

Beryllium The material I owe to Professor John Chipman of M I T The purity is said to have been about 99 7 to 99 8 per cent with possible inclusion of oxygen It was from the same batch as a specimen whose tensile behavior under pressure has been reported elsewhere (7) Beryllium is the most incompressible of the elements examined here Acceptance of the data at their face value would indicate a compressibility increasing with pressure This was not borne out, however, by the independent measurements in the 40,000 apparatus. The best course is to assume a linear relation between pressure and volume between 25,000 and 100,000 The table does not list the intermediate volumes in order to give no false impression about the accuracy The most important result is that there is no marked transition below 100,000.

Carbon (graphite) The material was single crystal Ceylon graphite in sheets of the order of 005 inches thick which I owe to the courtesy of Sir K. S Krishnan a number of years ago. It was cut into discs with a tubular cutter The discs were then stacked and assembled in the indium sheath Measurements have been previously made and published on the same material to 25,000 (8); measurements were not now re-

TABLE II

VOLUME OF VARIOUS ELEMENTS

Pressure kg/cm²	Be	C (Graphite)	Mg	Al	Si	Phosphorus Black	Phosphorus Violet	Ti	Mn	Ge	As	Zr	La	Ce	Pr	Nd	Th	U
1	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
25,000	978	947	943	970	978	935	903	978	961	968	955	974	917	797	927	935	962	978
30,000	No transition	940	935	966	974	927	885	No transition	956	964	947	967	904	788	916	925	952	973
40 000		929	919	958	968	912	853		947	956	933	956	882	770	896	906	937	966
50,000		919	904	951	962	† 899 849	829		939	949	921	946	863	756	878	889	924	960
60,000		911	890	944	957	837	809		932	942	911	937	846	744	863	873	913	955
70,000		903	878	937	952	825	793		926	935	903	929	832	732	849	858	904	951
80,000		896	866	929	948	816	780*		922	929	896	922	819	722	836	845	897	947
90,000		890	856	922	944	807	667		918	923	890	916	808	714	823	833	891	944
100 000	945	885	847	915	940	799	660	937	915	917	884	910	798	708	811	822	886	941

† Reversible transition * Irreversible transition at 85,000 from violet to black Volumes 0 773 and 0 670

peated in the 40,000 apparatus. The results should be fairly good, because the slope of the curve obtained with the 25,000 apparatus fits on smoothly with the results now found

Magnesium This was from stock obtained a number of years ago from the Research Laboratory of the Aluminum Company of America and had been especially purified It was used directly, without the intervention of an indium sheath, the mechanical softness being sufficient The results therefore do not depend on any corrections for the effect of the sheath The compressibility has been previously measured (9) only to 12,000 kg/cm². The fiducial volume at 25,000 was assumed to be 0 943 by extrapolation of the former results according to the formula

$$-\Delta V/V_0 = 29\ 50 \times 10^{-7} p - 26\ 7 \times 10^{-12} p^2$$

The slope at 25,000 of the new results agrees as well as could be expected with the extrapolated slope, being 0 017 against 0 016

Aluminum The material was cut from a Bureau of Standards melting point sample. Four runs were made two with an indium sheath and two without The agreement between the two sets was not as good as desirable, the volume at 100,000 given by the former being 0 903 against 0 915 by the latter The latter was made the basis of the results in the table, since it is presumptively more correct because of the absence of correction for the sheath. The variation of compressibility given by this series, however, is presumptively not correct, a slight increase of compressibility with increasing pressure being indicated, in opposition to the definitely indicated decrease of compressibility of the much more accurate measurements by the method of linear compressibility, as yet unpublished, to 30,000 The course was therefore adopted of showing a linear decrease of volume in the table between 25,000 and 100,000.

Silicon This material I owe to the kindness of Dr. W Shockley of the Bell Telephone Laboratories, it had been highly purified There are no previous measurements of the volume to high pressures The fiducial volume at 25,000 was calculated from the absolute potentiometer setting at contact This value lies smoothly enough between the atmospheric volume and the values at higher pressures The only previous determination of the compressibility of silicon appears to have been by T. W. Richards (10) over a pressure range of 500 kg/cm²; his value was 3.1×10^{-7}. This is much lower than the value indicated by

this new work. The early specimens of silicon were notoriously impure, and inadequate impurity is doubtless the major source of the discrepancy

Phosphorus 1. *Black phosphorus.* This was from my old stock, made from yellow phosphorus ar 12,000 kg/cm² and 200° C. some 20 years ago. There are no other measurements of the volume at high pressures. The fiducial volume at 25,000 necessary in the present calculations was taken from the absolute potentiometer setting Black phosphorus has a transition with comparatively large change of volume which runs with increasing pressure at 55,000 or 60,000 The reverse transition, however, with decreasing pressure does not run above 25,000, and therefore was not observable with the present set-up The fact that it does run, and that the transition is therefore of the thermodynamically reversible type, was established in two ways by the return of volume to normal value at atmospheric pressure and subsequent repetition of the entire pressure cycle when the measurements were repeated on the same sample in the second piezometer, and by X-ray determinations of the structure of the material after exposure to 100,000 The X-ray examination was most kindly made by Professor B. F Warren of M I T. who found the same normal black phosphorus structure which he had previously determined In the table the transition pressure is indicated as 50,000, this can be only rough It is probably much closer to the lowest pressure at which the transformation runs spontaneously with increasing pressure than to the pressure of thermodynamic equilibrium Naturally the volumes indicated in the table for the low pressure phase had to be obtained from the readings with increasing pressure only, instead of being an average of increasing and decreasing as usual.

2. *Violet phosphorus* This also was from my old stock, formed at about the same time as the black phosphorus and described in previous publications (11). Only one run was made with this, and the volumes in the table are obtained from the readings with increasing pressure only. This was necessary because between 80,000 and 90,000 the violet is transformed irreversibly to black, as is indicated in the table. The identity of the transformation product was again most kindly established by Professor Warren by X-ray analysis, who found the conventional black phosphorus lines, but much broadened, indicating a fine grained and distorted structure, as would be expected from the manner of formation Professor Warren also made an X-ray examination of the original violet phosphorus and found a line pattern somewhat better developed than the line pattern of many other varieties of red phosphorus. Up to the present, however, he has not been able to index the pattern of either this or any of the other varieties so that for the present the exact identity of this material is not known.

The markedly greater compressibility of violet phosphorus in comparison with black is to be noted This is in the direction to be anticipated. The transformation of violet to black phosphorus has already been accomplished at a pressure of 40,000 kg/cm² combined with plastic flow in shear (12) The transformation found in this paper is the first time that it has been accomplished by pure hydrostatic pressure The great efficacy of shearing stress in promoting a transition which is thermodynamically possible but which is resisted by internal viscocity is apparent.

Titanium This was from a lot recently obtained from A D Mackay, said to be of 99 per cent purity It was hard and brittle, and was one of the most incompressible of the substances measured here As in the case of beryllium, the measurements taken at their face value indicate a compressibility which is least at the lower end of the range, increasing somewhat to a roughly constant value at pressures over 50,000. This is not in line with the results obtained with the 40,000 apparatus, which indicated a normal decrease of compressibility with rising pressure up to 40,000. The best that can be done with the present results is to assume a linear relation between volume and pressure up to 100,000, and to take the volume actually obtained at 100,000 as giving the best mean compressibility The most important result is that there is no large transition Only a single piezometer was used.

Manganese This material was obtained through the kind offices of Dr. B A. Rogers before the war from the U S Bureau of Mines in Salt Lake City The analysis given was 1 02% Ni, 2 33% Cu, 0 1% Si, balance Mn. The compressibility was not measured in the 40,000 apparatus, the fiducial volume at 25,000 was obtained from the absolute potentiometer setting. The compressibility thereby indicated for the low pressure end of the range fits on smoothly with that obtained with the present apparatus above 25,000. In view of the complicated crystal structure of manganese it might perhaps have been anticipated that it would exhibit transitions.

Perhaps the comparatively large amount of copper may have suppressed such a transition.

Germanium This I owe to the kindness of Professor Lark-Horovitz. It had been used by him in his low temperature investigations of the Hall effect and was of his "N" type. This was measured also in the 40,000 apparatus, the volume at 40,000 obtained with it was 0 952 against 0.956 above

Arsenic. This was from my single crystal stock, the same as that used in previous measurements (13), and known to be of high purity The effect of pressure on this substance is known to be complicated; measurements of the linear compressibility to 12,000 kg/cm² indicated great differences in different directions and a condition of not well defined internal equilibrium The volume compression has been measured to 25,000 and the fiducial volume at 25,000 was taken from those measurements (3)—no measurements were made with the same apparatus to the new range of 40,000. The present results do not join on quite smoothly with the former ones to 25,000, the new ones giving a higher compressibility at the low end of the range The former results gave a volume decrement between 20,000 and 25,000 of 0.0062, and the new results between 25,000 and 30,000 of 0.075. There was no perceptible permanent change of volume after the first application of 100,000

Zirconium This was from the same specimen as that previously measured (14) to 12,000. It was obtained from the laboratory of the Philips Lamp Works in Eindhoven, was soft and malleable and presumably of high purity Measurements to 100,000 were made in only a single piezometer The fiducial volume at 25,000 was obtained from measurements with the 40,000 apparatus. This gave for the volume at 40,000 0.960 against 0 956 above No transition was found; the compressibility drops smoothly with increasing pressure

Lanthanum This was obtained from Mackay, without statement of the probable purity It was shipped under oil to avoid oxidation, was soft, and had every appearance of sound, homogeneous, pure metal. This was the first measured of four rare earth metals in consecutive places in the periodic table, namely La, Ce, Pr, and Nd. Very little work has been done on these previously under pressure. Cerium, however, is known (15) to be anomalous, having a rather large transition near 7,000 and the low pressure phase, being one of the few substances with a compressibility increasing with increasing pressure. It suggested itself that the other rare earth metals might also show abnormalities; the only one found was a transition of lanthanum with .0026 volume change at 23,400 kg/cm².

Measurements were made on lanthanum to 100,000 in only a single piezometer. It was also measured in the 40,000 apparatus and the fiducial volume at 25,000 obtained from those measurements Since lanthanum is among the more compressible of the substances measured here the results may be accepted with some confidence. The volume at 40,000 given by the 40,000 apparatus was 0 881 against 0 882 above.

Cerium This was obtained from Mackay at the same time as the lanthanum and the same remarks apply to it Measurements in the 40,000 apparatus gave for the volume at 40,000 0.766 against 0.770 above. It will be seen that no new anomalies were found above the transition, and the compressibility of the high pressure phase decreases normally with increasing pressure. The data to 40,000 should be consulted, they differ materially at low pressures from the previous data

Praseodymium. This was obtained from Mackay and the same remarks apply as to lanthanum and cerium Measurements were made in both the 40,000 and the 100,000 apparatus, for the latter only a single piezometer was used. No anomalies were found, at either high or low pressures. The volume at 40,000 given by the 40,000 apparatus was 0 893 against 0 896 with the 100,000 apparatus

Neodymium. This was also obtained from Mackay, and the same remarks apply as to the three other rare earth metals. Measurements to 100,000 were made in only a single piezometer. The volume obtained with the 40,000 apparatus at 40,000 was 0 905 against 0 906. No anomalies were found in any part of the range

Thorium. This was also obtained from Mackay. It was in the form of rolled sheet, 0.004 inches thick. The purity was not stated. It was punched into discs, which were stacked for the measurements to 100,000, using an indium sheath as usual. Only a single piezometer was used to 100,000 and no measurements were made with the 40,000 apparatus. No anomalies were found in the high pressure range The compressibility of thorium has been previously measured (16) to 12,000 for which the formula was found:

$$\Delta V/V_0 = -18.15 \times 10^{-7} p + 11\ 22 \times 10^{-12} p^2$$

The fiducial volume at 25,000, 0.962, was obtained by extrapolation from this formula At 50,000 the same formula gives 0.912 against 0 924 found above

Uranium This was old stock of unknown origin which I had had for a number of years. It is one of the more incompressible of the elements measured here, so that the results are relatively less reliable The behavior found was normal in every respect Uranium is mechanically much softer than either beryllium or titanium, and no indication of an anomalous increase of compressibility was found The fiducial volume at 25,000 was obtained from the 40,000 apparatus, which gave for the volume at 40,000 0.9676 against 0 966 above

Certain Compounds In Table III the volumes of nine compounds are given the sulfides, selenides and tellurides of zinc, mercury and lead These have already been measured (17) to 50,000, the material used in the new measurements is the same as that of the old

TABLE III

VOLUME OF VARIOUS COMPOUNDS

Pressure kg/cm²	ZnS	ZnSe	ZnTe	HgS	HgSe	HgTe	PbS	PbSe	PbTe
1	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
25 000	972	955	950	922	853	870	933	938	944
30,000	968	950*	944	920	844	863	928	932	930
40,000	961	940	933*	916	829	847	918	922*	930*
50,000	954	930	922	912	816	832	909	888	884
60,000	947	921	911	906	805	817	900	877	869
70,000	940	912	899	899	795	803	892	867	855
80,000	934	904	888	892	788	790	886	858	842
90 000	929	895	878	885	782	777	881	849	831
100,000	924	887	868	879	777	765	876	841	820
		* Small transition at 38 000	* Small transition here					* Transition at 45,000 Vols 0 917 and 0 893	* Transition at 45,000 Vols 0 925 and 0 892

ZnS was measured in the form of sphalerite, the form wurtzite is known to be changed by pressure and shear irreversibly to sphalerite (18) Nothing notable was found in the new range At 50,000 the volume was formerly found to be 0 951, to be compared with 0 954 found now

ZnSe was formerly found to have a transition in the neighborhood of 38,000 kg/cm² with volume discontinuity of 004 This is too small to be definitely indicated in the present results, which were smoothed right over the transition The volume at 50,000 given by the previous measurements was 0.931 against 0 930 now.

The former measurements on ZnTe gave a transition with volume discontinuity of 0.005 in the neighborhood of 40,000. This transition was perceptible in the readings with increasing pressure with one of the piezometers, but not with the other, which was more irregular than usual. The results in Table III are accordingly smoothed over the transition. At 50,000 the former value of the volume was 0 907 against 0.922 given now. The difference is greater than usual and is doubtless connected with smoothing over the transition.

The measurements with HgS were not as satisfactory as desirable The material was the red sulfide, previously used to 50,000 The first run to 100,000 gave an abnormally high compression up to 80,000, and then a further volume discontinuity indicating a transition. Unfortunately the slider stuck because of viscosity in the transmitting medium (this was before this defect in the apparatus had been corrected) with decreasing pressure, and the results of the run were discarded. The run with the second piezometer gave perfectly satisfactory readings on the identical specimen, except that the compression was markedly less One would suspect a permanent change of form after the first application, except that recovery of the initial volume at atmospheric pressure had been perfect The present measurements indicate an increase of compressibility with pressure at the low end, it is questionable how much of this is real. The volume found in the former measurements at 50,000 was 0 892 against 0 912 found now. The difference is larger than usual and again indicates some unusual occurrence, X-ray analysis of the final product would be desirable.

The HgSe was material which had previously been exposed to 50,000. It is known to have a large transition near 7,500, which naturally did

not figure in the present work The volume previously found at 50,000 was 0.820 against 0.816 found now. The high pressure measurements seem conventional enough; the decrease of compressibility with increasing pressure is perhaps somewhat greater than normal

The HgTe was from the same batch of synthetic material as that formerly used, but this particular piece had not been formerly exposed to pressure. It was previously found that HgTe decomposes slowly under pressure to the elements This decomposition prevented former measurements of the compressibility, but did not prevent the establishment of a reversible transition near 12,000 with 8 4 per cent volume change, slightly less than the change of HgSe In this new work the decomposition was not encountered, doubtless because the volume was so much smaller and the application of pressure so much more rapid, 20,000 in the preliminary application being reached in two or three minutes. As a consequence of this there are no low pressure compressibilities which could be used by extrapolation nor any direct measurements to give the fiducial volume at 25,000. The value used in the table, 0.870, is a guess based on the known volume of HgSe and the known volume discontinuities at the transitions The high pressure measurements appear normal enough The compressibility at high pressures drops off with increasing pressure much less than it does for HgSe, and the volume curves cross.

The PbS was a piece which had been previously exposed to 50,000 It is known that there is a transition just below 25,000, which naturally did not appear in this work except as it enters the fiducial volume at 25,000, which was taken from the former measurements The volume at 50,000 given by the former measurements was 0 901 against 0 909 found now

PbSe has been previously found to have a polymorphic transition at 43,000 with volume discontinuity of 0.016. The transition was found with these new measurements with a somewhat larger volume change, 0.024. The new value is doubtless to be preferred, since the transition point is so near the end of the former pressure range that the transition may not have run to completion. The volume at 50,000 given by the previous measurements was 0.882 against 0.888 found now. Above the transition the compressibility falls off normally with increasing pressure. The compressibility of the high pressure phase is not markedly different from that which would be extrapolated from the low pressure phase.

The PbTe had not been used in the former measurements to 50,000 but had been seasoned by an application of 30,000. Again, as in the case of PbSe, the previous measurements showed a transition at about 42,000 The volume change found was 0 009 The transition was found in the present work, but with a much larger volume change, 0.033. Doubtless the former low value is to be explained by incomplete running of the transition The volume previously found at 50,000 was 0 900 against 0 884 found now. The difference can be almost entirely explained by former incomplete running of the transition.

Quartz Crystal and Six Glasses One point of interest in measuring the glasses was to find whether the abnormal increase of compressibility with increasing pressure found at low pressures persists at high pressures In the case of quartz glass it had already been found (19) that there is a reversal near 35,000. The interest in measuring quartz crystal was to compare it with the glass. The three glasses "A", "C", and "D" in the following were from the same stock as that used in previous measurements (20) of the effect of pressure on rigidity The glass was originally obtained from Dr J T Littleton of the Research Laboratory of the Corning Glass Works. "A" was a potash lead silicate of very high lead content, "C" was a soda potash lime silicate, and "D" a soda zinc borosilicate. The quartz glass was from ordinary laboratory stock, selected to be free from visible imperfections The quartz crystal was provided by Professor Birch, who had it worked to the special shape required for measurement in the 40,000 apparatus. After the measurements to 40,000 I cut from the specimen a smaller piece for measurement to 100,000. The borax glass was also provided by Professor Birch, from the same stock as that used by Dane and Birch in their measurements of the effect of pressure on viscosity (21).

The volume at 40,000 for quartz crystal found with the 40,000 apparatus was 0 921, against 0.926 given by the 100,000 measurements. The cubic compressibility of quartz crystal is also obtainable from previous measurements (22) of the linear compressibilities in different directions up to 12,000. The formula, corrected for my improved compressibility of iron, is

$$\Delta V/V_0 = -26.45 \times 10^{-7}p + 22.6 \times 10^{-12}p^2.$$

This formula gives by extrapolation for the

TABLE IV

Volume of Quartz Crystal and Six Glasses

Pressure kg/cm²	Quartz Crystal	Quartz Glass	Glass "A"	Pyrex Glass	Glass "C"	Glass "D"	Borax Glass
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000
25,000	0.946	.923	.934	.921	.945	.932	.877
30,000	.939	.909	.923	.907	.936	.924	.866
40,000	.926	.885	.905	.885	.920	.909	.845
50,000	.914	.864	.890	.867	.905	.894	.825
60,000	.902	.847	.875	.851	.891	.880	.808
70,000	.892	.832	.862	.838	.878	.867	.792
80,000	.883	.819	.849	.827	.866	.855	.778
90,000	.875	.808	.838	.817	.854	.844	.765
100,000	.868	.798	.828	.809	.842	.834	.753

volumes at 25,000, 30,000, and 40,000 0.948, 0.942, and 0.930 respectively. The agreement with the values of Table IV is as close as could be expected for an extrapolation of this magnitude.

Quartz glass, measured in the 40,000 apparatus, gave for the volume at 40,000 0.881 against 0.885 in Table IV. Measurements have also been previously made to 50,000. The previous volumes at 25,000, 30,000, 40,000, and 50,000 respectively were 0.928, 0.912, 0.884, and 0.861. Both the previous measurements to 50,000 and the new ones to 40,000 show well the reversal in $\left(\frac{\partial^2 v}{\partial p^2}\right)_\tau$ near 35,000. The measurements in Table IV to 100,000 do not show this so well, however, the point of reversal being too near the lower end of the range. It will be noticed that the compressibility of the glass drops off with increasing pressure, in the range above 40,000 where it has become normal, more rapidly than that of the crystal. This is to be expected.

The volume of glass "A" given by measurements in the 40,000 apparatus was 0.904 at 40,000 against 0.905 found now. The 40,000 measurements indicate a break in direction near 20,000, the glass being more compressible above this pressure than would have been extrapolated from the volumes at lower pressure. This behavior is not suggested by anything in the present range, the compressibility dropping off smoothly with increasing pressure.

Pyrex glass has been found previously to have the same abnormal increase of compressibility with pressure as exhibited by quartz glass. Previous measurements had not extended above 12,000. New measurements on pyrex up to 40,000 show that the anomaly vanishes in the neighborhood of 25,000. The volume at 40,000 found with the 40,000 apparatus was 0.887 against 0.885 of Table IV above. In the range of Table IV compressibility drops normally with increasing pressure.

Glass "C" measured in the 40,000 apparatus shows the same sort of anomaly in the neighborhood of 20,000 as glass "A." The behavior appears to be normal in the range above 25,000 covered in Table IV. The volume at 40,000 found with the 40,000 apparatus was 0.917 against 0.920 found above.

Glass "D" measured in the 40,000 apparatus shows the same type of anomaly as "A" and "C," except that it is even more pronounced and occurs at a pressure somewhat below 20,000 instead of above it. The volume at 40,000 given by the 40,000 apparatus was 0.895 against 0.909 above. The discrepancy is by far the largest of any found in this paper. All the measurements appeared normally good, and the explanation does not suggest itself. If the anomaly just below 20,000 were associated with a transition, and if this were suppressed in the high pressure measurements, perhaps because of the rapidity with which pressure was increased, the discrepancy would be qualitatively explained. However, a transition of this sort in a glass would be something new.

Borax glass, measured in the 40,000 apparatus, showed no low pressure anomalies. The relation between volume and pressure is definitely not reproducible by a second degree expression in the pressure, the initial rate of drop of compressibility compared with that at higher pressures being too high. At 40,000 the volume given by the 40,000 apparatus was 0.835, against 0.845 above. The discrepancy is larger than usual, but so also is the absolute change of volume. Borax glass is the most compressible of the glasses measured here, quartz glass is next. The shape of the curves of volume against pressure is not the same for these two glasses; they draw together between 25,000 and 50,000, and from 50,000 on draw apart again by a small amount.

Discussion

Perhaps the most interesting question raised by an extension of volume measurements into a new field of high pressure is whether there is any indication of the atomic break-down to be expected at astronomical pressures. Ultimately, at high enough pressures, it has been shown by Jensen (23) and others that the perfect gas law will be followed, or volume will be inversely as the pressure. This means that ultimately log vol will be linear in log p, with a slope of unity. In Figure 5, $\log_{10}$ vol is plotted against $\log_{10} p$ for the five alkali metals of this paper, for lanthanum, the next most compressible metal of this paper, for borax glass, and for CsBr, one of the most compressible of the salts, the data for which have been determined in a previous paper (24) With one exception, the curves are all concave downward. If curvature continues in this direction, the volume will vanish at infinite pressure. Asymptotic approach to a finite volume at infinite pressure would obviously demand a reversal of curvature. Now all the early equations of state, before the possibility of atomic disintegration was visualized, demanded almost without exception a finite limiting volume at infinite pressure These high pressure measurements are sufficient to show the definite inadequacy of this point of view. Further than this, the curves do not suggest any very definite conclusions. They are obviously still a long way from approaching the limiting slope of unity, and might equally well be headed for other limiting slopes, which would mean that ultimately the volume becomes proportional to some power of the pressure other than the first.

Especial significance should doubtless be attached to the curve for caesium There are two breaks in this curve corresponding to the two polymorphic transitions The lower transition at 23,000 has a small volume change and the course of the curve is hardly affected on passing through it. The higher transition at 45,000, however, is something quite different. The volume change is much larger, and the high pressure phase is drastically different, because for it log vol against log p is concave upward, the only example of it. This is the direction of curvature consistent with a finite volume at infinite pressure, and is not the sort of thing associated with the atomic breakdown contemplated by Jensen. A plausible inference would seem to be that there may be a large number of intermediate episodes on the way to complete atomic disintegration. It seems not unreasonable to expect that the pressure domain beginning at roughly 10^5 or 10^6 atmospheres may be a domain of as much detail and structure, at present entirely unsuspected by us and beyond present theoretical attack, as the complex atomic domain of ordinary experience.

The high pressure end of the curve for potassium shows indications of an approaching reversal of curvature like that of caesium. Experimental error, however, makes this more uncertain, the large effect for caesium would seem to be beyond possible experimental error.

The curves for borax glass and for caesium bromide cross, that of the latter runs roughly parallel with that of the metals The crossing indicates an abnormally high compressibility in the borax glass at the low pressure end of the range This is what might be expected in a glass, the initial effect of increasing pressure being to remove the "slack" between the molecules, as in a liquid

Incidentally, any crossing of the volume curves is inconsistent with a universal one parameter relation between volume and pressure, of which the simple one constant equation of Murnaghan (25) is a recent example Murnaghan's more complicated equations, with two or more disposable constants, would be required to represent all the present results

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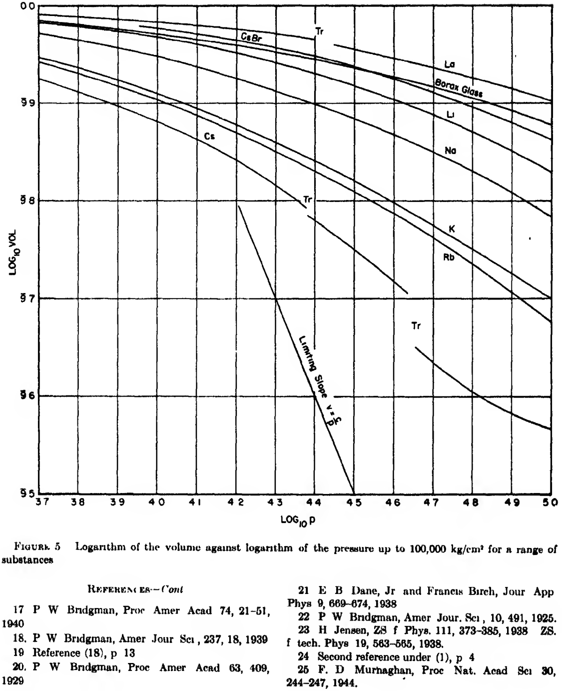

FIGURE 5 Logarithm of the volume against logarithm of the pressure up to 100,000 kg/cm² for a range of substances

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ROUGH COMPRESSIONS OF 177 SUBSTANCES TO 40,000 KG/CM²

By P. W. Bridgman

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Introduction

In a previous paper (1) an apparatus has been described for the rapid determination of the compression of solids at room temperature to high pressures, and the compression of 61 fairly compressible solids determined with it to 25,000 kg/cm². It was definitely not the intention to push this apparatus to the limit, but to use it as a tool of routine exploration in a range in which there would be no danger of fracture. It now appears that the limit formerly set was too conservative, for the same apparatus with minor modifications has now been carried regularly to 40,000, and the compression of 177 substances determined with it. Each substance involves two applications of maximum pressure, a preliminary "seasoning" application and the second stepwise application, up and down in steps of approximately 2,000 kg/cm², giving 43 readings in all. This has been accomplished with no fracture or measurable change of dimensions of the main pressure vessel. The short carboloy pistons, however, with which pressure is produced do not stand up indefinitely in this higher range, but have to be renewed from time to time. Failure of the piston is foreshadowed by the appearance of minute cracks, and since the piston can still be used several times after the first cracks appear, this has proved no disadvantage. One catastrophic failure occurred in the course of this new work. This was a failure of the steel column by which pressure is transmitted to the short carboloy piston, the column having been designed for the lower range of 25,000. Fortunately it was possible to redesign the column for the higher pressure range, and no further trouble has been encountered.

The materials investigated in the following have been selected as of interest from several points of view. The accuracy of the measurements naturally is greater for the more compressible substances, so that, in general, highly incompressible substances are to be avoided. Even these may be examined with profit, however, with regard to the possible existence of new polymorphic forms. There is no one guiding motif in the selection of the following material. The measurements have been made rather in the spirit of "scientific knitting," done in spare time between more systematic and important investigations. Since these measurements are mostly new, it has seemed worth while to at least record them.

The detailed presentation of data now follows, grouped into classes of substances.

Detailed Data

Plastics. Some 38 different plastics were measured, collected from a number of sources to have as wide a range of composition as possible. It was anticipated that there might be various transitions of higher orders among the plastics, that is, discontinuities in the various derivatives of volume, as a result of different stages of alignment of the long molecules. This did not turn out to be the case, however, but the curves were in almost all cases smooth.

The first six plastics shown in Table I were ordinary articles of commerce, taken from the laboratory stock. The Bakelite was clear amber stock, perhaps 25 years old. The "new" hard rubber was perhaps two or three years old, and the "old" about 25 years old. The purpose in trying rubber of two ages was to test whether there is any slow change with time. I owe to the courtesy of the du Pont Company the specimens of nylon and "Teflon" (polytetrafluorethylene), No. 29 in the table. The nylon 6–10 was cut from a sheet about 0.25 inch thick. The

TABLE 1

COMPRESSION OF VARIOUS PLASTICS

Pressure kg/cm²	Leucite	Polystyrene	Cellulose Acetate	Bakelite	Hard Rubber new	Hard Rubber old	Nylon 6–10	Nylon 6–6 unoriented	Nylon 6–6 oriented	α-Beetle Filler	Aeroglass 4121	Laminac 4201	Melmac 404	Melmac 1079	Melmac S–6004	48,000	41,000	46,000	2060–38
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
2,500	0367	0409	0468	0240	0316	0360	0385	0331	0380	0241	0437	0350	0226	0237	0182	0313	0279	0347	0370
5,000	0671	0724	0784	0438	0610	0642	0655	0594	0665	0439	0712	0599	0421	0434	0331	0545	0510	0619	0656
10,000	1097	1200	1189	0760	1045	1068	1060	0961	1061	0757	1136	0967	0741	0754	0567	0894	0853	1028	1098
15,000	1387	1519	1486	1022	1345	1372	1348	1233	1340	1000	1427	1245	0992	1004	0753	1148	1119	1324	.1417
20,000	1611	1756	1717	1235	1573	1600	1570	1444	1559	1202	1658	1469	1199	1208	0906	1359	1337	1554	1656
25,000	1796	1946	1905	1413	1760	1785	1749	1617	1739	1371	1841	1650	1368	1376	1035	1535	1520	1742	1846
30,000	1949	2104	2065	1564	1917	1938	1900	1768	1893	1512	1996	1803	1509	1516	1149	1686	1671	1900	2004
35,000	2078	2240	2200	1695	2050	2070	2029	1899	2024	1632	2127	1935	1632	1636	1248	1810	1803	2031	2138
40,000	2184	2359	2318	1812	2166	2188	2139	2016	2136	1739	2241	2052	1737	1738	1334	1916	1919	2146	2252

TABLE 1—Continued

COMPRESSION OF VARIOUS PLASTICS

Pressure kg/cm²	M–1805	M–2348	M–1364	M–2347	M–2343	M–2345	M–2346	M–2344	M–2342	Teflon	Fluorine Plastic	Silicone 160	Silicone 181	Silicone 180	Silicone 167	Silicone 120	Silicone 125	Silicone 150	Silicone Glass filled
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
2 500	0553	0548	0522	0435	0383	0424	0399	0435	0474	0527	0398	0835	0746	0653	0669	0814	0872	0737	0334
5,000	0874	0897	0863	0760	0676	0762	0707	0781	0775	0847	0673	1182	1090	0967	1001	1213	1284	1112	0580
10,000	1319	1331	1300	1201	1116	1217	1156	1262	1213	1453*	1037	1580	1529	1368	1385	1676	1734	1522	0930
15,000	1621	1639	1606	1504	1440	1526	1467	1569	1525	1694	1282	1796	1788	1595	1580	1901	1974	1757	1177
20,000	1852	1876	1836	1733	1685	1763	1698	1797	1766	1875	1474	1951	1995	1779	1729	2081	2153	1941	1378
25,000	2040	2066	2024	1917	1880	1952	1883	1979	1960	2019	1628	2081	2176	1937	1852	2229	2303	2091	1551
30,000	2194	2222	2178	2074	2042	2108	2038	2130	2118	2143	1755	2194	2336	2076	1960	2351	2429	2230	1708
35,000	2321	2351	2306	2206	2178	2234	2167	2262	2250	2248	1862	2297	2475	2197	2055	2455	2531	2330	1835
40,000	2430	2460	2416	2315	2293	2336	2275	2375	2362	2339	1956	2390	2592	2303	2139	2545	2614	2424	1955

* Transition at 6,500.
Vols. 1004 and 1230

nylon 6-6 was provided in a rod of approximately 0.5 inch diameter (unoriented). The "oriented" specimen of this 6-6 nylon was produced by upsetting a cylinder originally 1 inch long by one-sided compression between the platens of a hydraulic press until the thickness was reduced to 0.085 inch. It required about 45,000 psi to do this. Plastics 10 to 15 inclusive I owe to the courtesy of the American Cyanamid Company. Their description of them is as follows.

Melmac 404; Melamine-formaldehyde, no filler, at present an experimental product.

Melmac S-6004; Melamine-formaldehyde, asbestos filler.

Melmac 1079; Melamine-formaldehyde, alpha cellulose filler

Beetle; Urea-formaldehyde, alpha cellulose filler.

Aeroglass 4121; Clear cast copolymer type, no filler.

Laminac 4201; Clear cast copolymer type resin similar to that used in laminating applications, no filler

Plastics 16 to 28 inclusive I owe to the kind offices of Dr. C. O Strother of the Linde Air Products Company, who obtained most of them from the Bakelite Corporation The description is given in the appended table

In addition to the plastics described in detail in the above table, four others obtained from Dr. Strother are described as follows. "Sample 206-38 is of the type known as a polyester resin. It is generally made by the reaction of a di-basic acid containing maleic acid with a glycol. This base resin is hardened with a vinyl material such as styrene. The samples marked 41000 and 48000 are phenolic formaldehyde types. Sample 46000 is a so-called glyptal. It is made by the reaction of a di-basic acid, such as phthalic, with glycerine or a like compound."

Plastic 30 is one of the experimental fluorine plastics developed during the war which I owe to the kindness of Dr. W. T. Miller of Cornell.

Plastics 31 to 38 inclusive are various silicone plastics which I owe to the courtesy of the Dow-Corning Research Laboratory. These silicones are described by the manufacturers as "Silastics," and various mechanical and electrical properties are given in their trade catalogue on silicones Silastics 120 and 125 contain approximately 50 per cent by weight of titanium oxide and 50 per cent of high polymeric methyl silicone. Silastics 160, 167, 180 and 181 contain approximately 60

	Formulation						Properties of Base Resin		
Designation	Base Resin			Plasticizer (plus stabilizer)			Sp Gr 20/20	Vinyl Chloride Content, Wt. %	Average Mol Weight
	Description	Wt %	Vol %	Description	Wt %	Vol. %			
M-1805	Polyethylene, Exp low mol. wt.	100	100	—	—	—	0 92	0	14–16,000 (Soln. Viscosity)
M-2348	Polyethylene, Stand. DYNH	100	100	—	—	—	0 92	0	18–20,000 (Soln Viscosity)
M-1364	Polyethylene Exp high mol. wt.	100*	100*	—	—	—	0 92	0	36–38,000 (Soln Viscosity)
M-2344	'Vinylite' VYHH Resin	98	97 5	Organo-tin heat stabilizer	2	2 5	1 36	87	55,000 (osmotic)
M-2345	'Vinylite' VYNS Resin	98	97 5	Organo-tin heat stabilizer	2	2 5	1 375	90	75,000 (osmotic)
M-2347	'Vinylite' VYNW-5 Resin	98	97 5	Organo-tin heat stabilizer	2	2 5	1 39	95	130,000 (osmotic)
M-2342	'Vinylite' VYNW-5 Resin	76 6	70	Organo-tin heat stabilizer	1 7	2 0	1 39	95	130,000 (osmotic)
				Dioctyl phthalate	21 7	28 0			
M-2343	'Vinylite' VYNW*-5 Resin	73 6	70 0	Organo-tin heat stabilizer	1 7	2 0	1 39	95	130,000 (osmotic)
				Tricresyl phosphate	24 7	28 0			
M-2346	'Vinylite' VYNW-5 Resin	76 0	70 0	Organo-tin heat stabilizer	1 7	2 0	1 39	95	130,000 (osmotic)
				Resinous Products G-25**	22 3	28 0			

Notes: *This resin contains an extremely small quantity of contaminating carbon arising in polymerization, hence, the dark gray color of molded plaque.
**Resinous type plasticizer reported to be a condensation product of sebacic acid, glycerol and ricinoleic acid.

per cent by weight of fillers and the balance is a high polymeric methyl silicone. The fillers are. 160—50 per cent zinc oxide and 50 per cent titanium oxide; 167—all titanium oxide; 180—50 per cent titanium oxide and 50 per cent silica, 181—all silica.

Omitting Melmac S-6004, a heavily filled plastic, and the filled α-Beetle, the range of volume compression under 40,000 is from .1737 for Melmac 404 to 2614 for Silicone 125-96, a range of about 50 per cent. The range of initial compressibilities is much wider than this, however The volume compression in the first 2,500 kg/cm² varies from 0.0226 to 0 0872, a range of nearly four fold That is, at the high pressures the initial differences tend to disappear. The silicones stand in a class by themselves, being characterized by a high initial compressibility. As already mentioned, no breaks in direction were found and the curves were all smooth. This does not mean, however, that the curves are all similar to each other, because a number of examples can be found of crossing of the curves Any such effects are, however, not on a large scale.

The only anomaly found in all these plastics is shown by Teflon This has, at 6,500 kg/cm², a discontinuity in volume, indistinguishable in all its traits of behavior from an ordinary reversible polymorphic transition. Since such transitions are ordinarily associated with change of lattice structure, and plastics are not, according to the ordinary point of view, endowed with a regular lattice structure, the occurrence of such a transition was unexpected. It would seem to indicate an unusually high degree of organization in the structure. Professor B. Warren, of Massachusetts Institute of Technology, was so kind as to make an X-ray analysis of a sample of teflon He reported: "There are too many sharp lines for this to be classed as the pattern of a truly amorphous material. It is not possible to say that the material is perfectly crystalline, but it is closer to crystalline than to the completely amorphous state."

Glasses. Six glasses were measured, for which the results are given in Table II. Of these, quartz glass was from laboratory stock, selected to be free from internal striations Pyrex was similarly selected from laboratory stock Glasses "A," "C," and "D" are from the same rods as those used a number of years ago in measuring compressibility and the effect of pressure on rigidity (2). I owe them to the courtesy of Dr. J. T. Littleton of the Research Laboratory of the Corning Glass works. Glass "A" is a potash lead silicate of very high lead content, "C" is a soda potash lime silicate, and "D" is a lead zinc borosilicate. The borax glass I owe to the courtesy of Professor Francis Birch, it is from the same batch as that used by Dane and Birch in their measurements of the effect of pressure and temperature on viscosity (3).

Of the six glasses investigated, all but the borax glass show anomalies of one sort or another which are all beyond any possible experimental error. The anomaly of quartz glass has already been investigated (4) in another apparatus up to 50,000 It was formerly found that its compressibility increases with increasing pressure at a constantly increasing rate until a pressure of 35,000, where there is a break in the direction of the tangent (transition of the second kind in the nomenclature of Ehrenfest), and from there on decreases normally with further increasing pressure This behavior is confirmed with the present apparatus The discontinuity in direction is now found at a somewhat lower pressure, 31,000 instead of 35,000 The best way of seeing this is to plot the first differences of volume from Table II against pressure. With regard to absolute values, the volume decrement at 40,000 found with the present apparatus is 0.1194 against 0 1163 previously. This difference is not necessarily all instrumental, because there is reason to think that quartz glass is not a perfectly well defined substance The anomaly of pyrex is similar in character to that of quartz glass, as is to be expected from the 81 per cent content of SiO_2 in pyrex The break in direction is at a somewhat lower pressure for pyrex, between 28,000 and 29,000 Pyrex has been formerly measured (5) over the range up to 12,000, and the initial increase of compressibility with rising pressure

TABLE II

COMPRESSION OF GLASSES

Pressure kg/cm²	Quartz Glass	Pyrex	"A"	"C"	"D"	Borax Glass
0	0000	0000	0000	0000	0000	0000
5,000	0141	0153	0159	0121	0144	0345
10,000	0295	0308	0300	0239	0281	0631
15,000	0452	0465	0425	0352	0411	0857
20,000	0610	0622	0535	0449	0542	1054
25 000	0772	0786	0656	0549	0678	1228
30 000	0933	0920	0770	0654	0806	1376
35,000	1068	1032	0866	0742	0927	1518
40 000	1194	1133	0964	0830	1049	1648

found. The volume decrement at 15,000, extrapolated from the 12,000 measurements, was 0.0462 against 0.0465 found now.

Glasses "A," "C," and "D" all show the same sort of anomaly, the reverse of that of quartz glass. It is natural to ascribe this to the silicate content of these glasses. The anomaly consists in a break in the direction of the tangent, but in the direction of an increase of compressibility rather than a decrease. Above and below the break the compressibility decreases normally with increasing pressure. For glass "A" the discontinuity in $\left(\frac{\partial v}{\partial p}\right)_\tau$ occurs at 21,000 and is approximately 0 00000045 in magnitude in the units of the table; for glass "C" it occurs at 22,000 and is 0.00000055 in magnitude, and for "D" it occurs at 18,000 and has a magnitude of 0 0000004

The anomalies in quartz glass and the silicates are thus one the inverse of the other, and would therefore seem to imply inverse mechanisms In the case of quartz some mechanism responsible for high compressibility goes out of action on reaching a certain pressure, and in the case of the silicates some new mechanism must come into action at a critical pressure Mechanical models are not difficult to imagine Thus if in the case of quartz the structure contained something analogous to dished flat springs, the increase of compressibility could be explained as a geometrical effect, the spring becoming flatter the further it was compressed and therefore offering less elastic resistance because of the diminishing arching effect, and the sudden termination of the effect could be explained by the opposite sides of the dished spring being compressed into mutual contact In the case of the silicates an analogous sort of mechanism can be imagined, only now the springs are parallel to the direction of stress and the two leaves do not begin to separate until a crucial pressure is reached. The X-ray structure of the glasses is known to be complicated enough and also to have sufficiently marked partial regularities to make it not unplausible to expect that mechanisms like these may exist.

Elements The measurements on the elements were made both for their own sake, and also to provide the fiducial volume at 25,000 which was necessary in reducing the measurements to 100,000 These latter are reported in the previous paper; there is an overlapping range between 25,000 and 40,000 which affords a check on the measurements. The comparison of the measure-

TABLE III

COMPRESSION OF VARIOUS ELEMENTS

Pressure kg/cm²	Lithium	Sodium	Potassium	Rubidium	Caesium	Beryllium	Titanium	Zinc	Germanium	Zirconium	Lanthanum	Cerium	Praseodymium	Neodymium	Uranium
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
2 500	0204	0334	0677	0696	0999	0024	0027	0040	0040	0026	0100	0109	0090	0078	0024
5,000	0389	0624	1152	1224	1585	0047	0052	0079	0078	0054	0194	0234	0174	0152	0048
10,000	0715	1115	1862	1982	2392	0094	0099	0154	0152	0111	0370	0549	0329	0289	0095
												(c)			
15,000	1005	1511	2374	2506	2981	0139	0143	0225	0213	0168	0526	1655	0471	0416	0139
20,000	1261	1836	2772	2920	3442	0181	0185	0293	0268	0220	0665	1864	0604	0536	0181
					(a)						(b)				
25 000	1485	2111	3093	3254	3908	0219	0224	0358	0323	0267	0827	2027	0729	0650	0219
30,000	1689	2350	3360	3530	4261	0256	0261	0420	0375	0312	0952	2154	0848	0757	0255
35,000	1872	2559	3584	3760	4559	0294	0297	0480	0426	0356	1072	2257	0961	0858	0290
40,000	2040	2740	3774	3954	4816	0329	0332	0537	0476	0399	1189	2342	1069	0955	0324

(a) Transition at 23 300 Compressions 3716 and 3776
(b) Transition at 23,370 Compressions 0755 and 0781
(c) Transition at 12,430 Compressions 0736 and 1504

ments in the overlapping range has been anticipated in the previous paper

The five alkali metals were from my stock, known to be of high purity. It is the same stock as that used in previous measurements (6), and reference is made to former papers foz the details of purification, etc. The caesium was freshly distilled from a glass capsule obtained from MacKay in 1937 and not opened until now. The distillation, which was slow at a minimum temperature, was necessary to remove the impurity of dissolved oxide. The details of the distillation were as in former work. For the present measurements the lithium was placed directly in the carboloy container, with no sheath of indium or other intermediary between it and the carboloy. Some misgivings were felt in doing this, because there had been previous evidence in the work to 100,000 that there might be chemical attack on the carboloy. None appeared in the present range, however, and the results should have the advantage of greater accuracy because of the absence of any second material in the piezometer. It was necessary to use a protecting sheath for the other four alkalies, however. This was made necessary both by their mechanical softness and their chemical activity. The sheath could not be made of indium or of lead, since both of these form alloys. The sofest metal which appeared feasible for the sheath was aluminum. The sheath was in the form of a double cup. The volume of the aluminum varied from 70 to 200 per cent of the alkali metal depending on the compressibility of the metal. The various corrections, including that for the compressibility of the sheath, averaged 10 per cent of the total volume decrement.

There are previous measurements on all of these alkali metals for comparison. For lithium the volume decrement at 40,000 previously found was 0.201 against 0.204 found now. For sodium the previous decrement at 40,000 was 0.273, against 0.274 now. For potassium the respective figures are 0.375 and 0.377. For rubidium the figures are 0.431 and 0.395. This large discrepancy is doubtless the fault almost entirely of the previous measurements. These were based on measurements by the method of linear compressibility up to 12,000, a method entirely unsuitable for this material because of its excessive mechanical softness. Furthermore, the theoretical calculations of Bardeen (7) had indicated that the previous values for rubidium were out of line with what was to be expected in the direction now found. The percentage discrepancy between the former and present measurements is greatest at the low pressure end of the range. For caesium the respective figures are 0.487 and 0.482. The new figure is to be preferred. The volume discontinuity at the transition of caesium at 23,300 kg/cm² formerly found agrees exactly with that now found.

The beryllium I owe to Professor John Chipman of M. I. T. It was said to be of 99.7 to 99.8 purity. For further particulars the paper describing the measurements to 100,000 should be consulted. There are previous measurements (8) of the compressibility of beryllium to 12,000. These give for the volume decrement at 10,000 0.0076 against 0.0094 now found. The new value is doubtless to be preferred, because of greater purity of the present specimen. However, it must be recognized that the absolute compressibility of beryllium is so low as to restrict the accuracy obtainable with the present apparatus.

The titanium was obtained from MacKay. It was said to be of 99 per cent purity, but was hard and brittle. It is not improbable that there is a very small transition in the neighborhood of 35,000. The values given in the table are smoothed across this. There are no previous measurements for comparison. Titanium is one of the least compressible substances measured with the present apparatus, with correspondingly smaller accuracy.

The zinc was single-crystal material obtained a number of years ago from Dr. A. W. Hanson at the University of Iowa and known to be of high purity. One of the objects of measuring zinc was to find whether the indium sheath exerts an effectively hydrostatic pressure on the specimen so that the resulting measurement is one of true volume compression, and not of some other combination of the elastic constants. Since the linear compressiblity of zinc is 8 times as great in one direction as the other, this is a particularly favorable material to show the effect if it exists. Three specimens were made, one with the cleavage plane perpendicular to the axis of the carboloy piezometer, one with it parallel, and one at 45°. The measurements did show a perceptible trace of the effect suspected, and in the expected direction. The volume compression on an arbitrary scale at the maximum pressure varied from 886 to 896. This is so very far from a factor of 8 to 1 that it is probably safe to assume that for most materials the stresses are sensibly hydro-

static The figures given in the table are the average for the three orientations, and therefore possibly a trifle low Previous measurements (9) have been made to 12,000 on the single crystal in different directions and the cubic compression calculated The previous value at 10,000 so calculated was 0 0299 against 0 0294 found now

The germanium I owe to the courtesy of Professor Lark-Horovitz It has been measured to 100,000 and reference is made to that paper for further details There are no other measurements Over the range to 40,000 the relation between volume and pressure fails markedly of being a second-degree relation The maximum deviation from linearity is at 12,000 instead of 20,000, and the change in direction in the general neighborhood of 12,000 is so abrupt as almost to constitute a transition of the second kind

Zirconium was cut from a specimen obtained many years ago from Eindhoven used in previous measurements (10) to 12,000 The volume decrement formerly found at 10,000 was 0 0103 against 0 0111 found now This is one of the more incompressible substances

Lanthanum, cerium, praseodymium, and neodymium were all obtained from Mackay, all fresh material shipped under oil The purity was not stated, but judging by the general appearance and mechanical softness the purity was high Three of these metals have been measured previously (11) to 12,000 by the method of linear compressibility The crystal system of cerium is cubic, and of the other three hexagonal close-packed Except for cerium it was therefore not legitimate to calculate volume compression from linear compression, but in view of the close-packed character of the hexagonal structure the error was probably not large

The compression previously found for lanthanum at 10,000 was 0 0339 against 0 0370 found now The present value is to be preferred both because of the presumptively greater purity and also because lanthanum is not in the cubic system The transition at 23,370 was not previously known, it runs cleanly with narrow region of indifference

Cerium is anomalous in two respects, there is a large transition with 8 per cent volume change at 12,430, and below the transition the compressibility increases markedly with increasing pressure, the volume decrement at 10,000 being 17 per cent greater than would be given by linear extrapolation from 5,000 Previous measurements showed the same abnormal increase of compressibility, and also a transition The transition, however, was at a much lower pressure, 7,500 kg/cm² It was found to be sluggish and the change of volume was not determined, the measurements having been made on a piece of wire, not an advantageous form of specimen The transition now found was sharp and rapid The new values are without doubt greatly to be preferred, the difference may well be ascribed to inferior purity of the former sample A still earlier exploration of a sample of cerium with still inferior purity had disclosed no transition at all It is, however, surprising that the pressure of the transition is so sensitive to impurity It would indicate that the impurity forms solid solutions, and probably with both phases and with different concentrations The previous measurements of volume compression, by linear compression of wire, were made only to 4,000 in order to avoid the effect of the transition Extrapolation to 5,000, assuming uniform compression in all directions, of the former measurements, gives 0 0269 against 0 0234 found now The new value is to be preferred

In view of the anomalies of both lanthanum and cerium, increasing from lanthanum to cerium, it was somewhat of a surprise that praseodymium, the next rare earth metal after cerium, shows no anomaly whatever, but the curve is perfectly smooth Its volume compression at 10,000, previously found, was 0 0326 against 0 0328 found now

The curve for neodymium is perfectly smooth There are no previous values for comparison

Minerals I am indebted for eleven minerals to Professor Francis Birch, who selected them from the collections of the Harvard Geology Department Professor Birch had them ground in his machine shop by Mr Harold Ames to the shape required for the measurements The truncated cone form was used, and indium was placed below the specimen, between it and the stationary piston, as well as on the sides of the cone and above it, in order to ensure as close an approach to true hydrostatic pressure as possible The specimens were all single crystals Two specimens of orthoclase were measured, one from Madagascar was clear, and the other from Spain was opaque with small black inclusions The olivine was gem material (peridot) from St John's Island, Red Sea, Egypt. The diopside was from De Kalk, N. Y The grossularite, a variety of garnet, had the indicated composition $Ca_3Al_2(SiO_4)_3$ The "garnet" was from Connecticut, and the hypersthene from Labrador

TABLE IV

COMPRESSION OF VARIOUS MINERALS

Pressure kg/cm²	Quartz Crystal *	Ortho-clase Mada-gascar	Labra-dorite	Calcite	Olivine	Diop-side	Grossu-larite	Garnet	Hyper-sthene	Ortho-clase Spain	Halite
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
10 000	0236	0171	0133	0134	0079	0088	0072	0071	0101	0175	0366
				(a)							
20 000	0441	0333	0260	0725	0156	0160	0140	0138	0191	0335	0664
30,000	0625	0488	0381	0887	0231	0245	0204	0200	0272	0484	0924
40 000	0792	0634	0495	1019	0304	0318	0264	0257	0347	0625	1160

(a) Two transitions

The results are collected in Table IV. There are previous measurements for a number of the minerals. For quartz, former measurements (12) to 12,000 give for the volume decrement at 10,000 0.0242 against 0.0236 found now. Extrapolating by a second degree expression to 40,000 the former measurements give a volume decrement of 0.0696 against 0.0792 actually found now. The extrapolation gives considerably too small a decrement at the high pressures, this is the usual direction of discrepancy. The two orthoclases differ little in compressibility, in spite of the great difference in appearance. Former measurements (13) to 12,000 gave at 10,000 0.0195 against 0.0171 and 0.0175 found now. Labradorite has not been previously measured. Calcite has been previously measured (14) to 50,000, in those measurements the two transitions between 10,000 and 20,000 were more carefully studied than here. In the present work the two transitions were not resolved. The former decrements at 20,000 and 40,000 were 0.077 and 0.096 respectively against 0.073 and 0.102 found now. The present results differ from the former ones in giving a greater compressibility in the range between 20,000 and 40,000. Of the remaining minerals previous measurements have been made only for halite. Previous measurements gave for the decrement at 20,000 and 40,000 respectively 0.0664 and 0.1130 against 0.0664 and 0.1160 found now. The close agreement in the results for the two varieties of garnet is to be noticed.

Substances with Transitions. Most of these were substances previously investigated (16), for which the transition parameters have been determined. There are, however, a few new ones, the transitions of which were discovered in the course of this work. Five substances with newly discovered transitions are deferred for listing in Table VII. The particular point in investigating these substances was to find the relative compressibilities of the two phases at the transition point. It had been previously found that in the majority of cases the high pressure phase, that is, the phase with the smaller volume, has the larger compressibility, a paradoxical result. The material was, in the case of those substances measured before, the same old stock, and reference is made to previous papers for a description of it. The few new materials will be described in due course. The results are shown in Table V.

The volume discontinuity of ammonium formate previously found was 0.0860 against 0.0860 found now. In general comment on the comparative volume decrements, the larger of two values is presumptively more accurate, the smaller value being due to incomplete running of the transition. This substance shows a drop in compressibility to approximately one half on passing from the low to the high pressure form.

Methylamine hydrochloride has two transitions, at approximately 5,000 and 25,000. The volume discontinuities previously found were 0.049 ± and 0.012 ± against 0.0520 and 0.0158 found now. There is no appreciable difference in compressibility of the two phases at 25,000. Not enough points were taken to determine the relative compressibility of the two low pressure phases. It is to be noted, however, that at low pressures the compressibility varies with pressure by an amount abnormally large for a solid.

The volume discontinuity of $CsMnO_4$ previously found was 0.0275 against 0.0241 now. At the transition pressure the high pressure form is approximately 11 per cent less compressible than the low pressure form.

Comparison of the present values for KCN with previous ones is not easy. It was previously found that KCN has at least four modifications. In order to obtain these, temperature was varied from dry ice temperature to 200° C. Most of the

TABLE V

SUBSTANCES WITH TRANSITIONS

Pressure kg/cm²	Ammonium Formate	Methylamine Hydrochloride	$CsMnO_4$	K C N	Ag CN	PbI_2	Cu_2I_2	Urea	Thiourea
0	0000	0000	0000	0000	0000	0000	0000	0000	0000 (i)
5,000	0386	0397 (b)	0270	0280	0466	0332 (f)	0133	0375 (h)	0619
10 000	0670 (a)	1186	0497 (d)	0539	0787	1014	0247 (g)	1328	0922
15 000	1940	1406	0938	0777	1041	1203	0717	1563	1162
20,000	2052	1601	1099	0990 (e)	1251	1359	0844	1759	1352
25,000	2157	1779 (c)	1246	2030	1433	1491	0958	1925	1511
30 000	2255	2099	1384	2166	1594	1604	1064	2066	1650
35,000	2348	2251	1516	2287	1741	1712	1164	2188	1776
40,000	2438	2398	1644	2402	1879	1810	1260	2295	1893

(a) Transition at 11,420, Volume decrements 0742 and 1853
(b) Transition at 5,530, Volume decrements 0436 and 0956
(c) Transition at 25,270, Volume decrements 1790 and 1948
(d) Transition at 13,430, Volume decrements 0643 and 0884
(e) Transition at 20,340 Volume decrements 1011 and 1885
(f) Transition at 5 150, Volume decrements 0369 and 0761
(g) Transition at 14,400, Volume decrements 0339 and 0702
(h) Transition at 5 490, Volume decrements 0411 and 1053
(i) Transition at 3,540, Volume decrements 0309 and 0512

TABLE V (Continued)

SUBSTANCES WITH TRANSITIONS

Pressure kg/cm²	Nitrourea	Semicarbazide Hydrochloride	Quinone	Guanidine Sulfate	d-Camphor	Ammonium Pentaborate	Potassium Pentaborate	Dextrose Sodium Iodide	$MgSO_4 \cdot 7H_2O$
0	0000	0000	0000 (l)	0000 (m)	0000 (o)	0000	0000 (q)	0000	0000
5 000	0354 (j)	0276 (k)	0611	1757	1365	0360	0751	0263	0235
10 000	1156	0525	0907	1951 (n)	1712	0606	0977	0494	0445 (u)
15,000	1383	0708	1300	2161	1962	0806	1171	0697	0844
20 000	1570	0864	1552	2284	2158	0984 (p)	1337 (r)	0880	0990
25 000	1725	0998	1763	2388	2319	1378	1549	1045	1139, 1412 (v)
30 000	1861	1119	1943	2480	2456	1529	1666	1196 (s)	1539
35 000	1981	1229	2095	2565	2577	1646	1767	1480 (t)	1644
40,000	2088	1332	2224	2647	2694	1741	1858	1693	1747

(j) Transition at 5,510, Volume decrements 0387 and 0911
(k) Transition at 9 470, Volume decrements 0469 and 0501
(l) Transition at 4,530, Volume decrements 0477 and 0568
(m) Three transitions below 5 000
(n) Transition at 10,460, Volume decrements 1968 and 2027
(o) Transition at 3,540, Volume decrements 0748 and 1229
(p) Transition at 23,300, Volume decrements 1092 and 1317
(q) Transition at 3,540, Volume decrements 0211 and 0663
(r) Transition at 20,340, Volume decrements 1348 and 1411
(s) Transition at 30,220, Volume decrements 1202 and 1364
(t) Transition at 37,190, Volume decrements 1542 and 1622
(u) Very sluggish transition between 10,000 and 15,000
(v) Probably two sluggish transitions in neighborhood of 25,000 Volume discontinuity of one about four times that of other

transitions are fast, but at low pressures and high temperatures there is one transition so sluggish that it could not be brought down to room temperature, and furthermore there was evidence at the higher temperatures of the capricious appearance of an absolutely unstable form. The present measurements gave evidence only of the high pressure transition, in the neighborhood of 20,000 This ran unusually sharply, and all the measurements on this substance were unusually good, the difference between readings with increasing and decreasing pressure being unusually small However, the volume change at the transition was now found considerably smaller than the previous value, 0 0874 against 0 102 The atmospheric density, calculated from the absolute position of the piston, was high, 1 64 against 1 52 given in I C T It is perhaps not inconceivable that on the initial seasoning application of pressure a small amount of the absolutely unstable phase appeared and maintained itself This is consistent with a larger than usual permanent change of volume after the seasoning application The present results show a 23 per cent drop of compressibility on passing through the transition from the low to the high pressure form

No evidence for a transition of AgCN was found in the present work Previously a sluggish transition with very small volume change, 0 001, was found in the neighborhood of 14,000

The volume discontinuity previously found for PbI_2 was larger than that found now, 0 049 against 0 039 The transition comes at such a low pressure that the change of compressibility on passing through the transition could not be established

The former and the present transition parameters for Cu_2I_2 agree very closely, the pressures are indistinguishable and the volume discontinuity was 0 0360 against 0 0363 now There is a 35 per cent increase of compressibility on passing through the transition to the high pressure phase The transition of thiourea has been previously studied, but only at temperatures of 100° or above Extrapolated to 25° the former measurements would give 3,460 for the transition pressure and 0 0139 for the discontinuity of volume against 3,540 and 0 0203 given above The transition pressure is too low to permit a determination of the relative compressibility of the two phases

Previous measurements on nitrourea disclosed no certain transition However, the pressure exploration was combined with high temperatures and it appeared that there were complex decomposition phenomena. It is probable that the transition was missed in the former work because of some irreversible transformation of the substance. In the present work a clean transition with 5 per cent volume change was found near 5,000 Any discontinuity of compressibility on passing through the transition is too small to be established

In previous work on semicarbazide hydrochloride the measurements were confined to temperatures of 75° or higher because the transition was too sluggish at lower temperatures. In the present measurements at room temperature the transition was very sluggish, running at 15,400 with increasing pressure and 3,540 with decreasing pressure Within these pressure limits the curves with increasing and decreasing pressure were parallel, indicating no appreciable difference of compressibility between the low and high pressure phases The mean transition pressure of the present work, 9,470, is markedly higher than the 5,500 extrapolated from previous work. The extrapolated volume discontinuity is about ten times that given in the table. Comparison of measurements with so sluggish a transition is not significant

The transition parameters obtained for quinone with the present apparatus are in much doubt, the transition limits being 4,000 kg/cm² wide. The former determinations were also in doubt, no determinations of volume discontinuity being attempted below 75° because of sluggishness of the transition The former volume discontinuity extrapolated is 0 0370 against 0 0091 found now Allowing maximum uncertainty to the extrapolation there would seem to be little doubt that the present volume discontinuity is too small. The present results give no sufficient evidence as to a discontinuity of compressibility at the transition

Guanidine sulfate has three transitions below 5,000 which run so sluggishly that a slow change of volume continues for some time after pressure has been released and the apparatus disassembled No attempt was made to resolve these transitions, but reference is made to the previous work There is also a sluggish transition near 10,000 for which a volume discontinuity of 0 0059 was found in the present work against 0.0071 formerly It seems probable, although not certain, that there is a moderate increase of compressibility on passing to the high pressure form through the transition at 10,000.

The transitions of d-camphor have been studied in two previous papers The phase diagram is

the most complicated of any substance yet investigated, there being probably eleven modifications up to 35,000. A number of these are sluggish and run only at elevated temperatures. In the present work the complicated change which starts with modification II and ends with III, perhaps passing through IV and V as intermediate forms, was found to run at a mean pressure of 3,540 against 2,700 formerly The present over-all change of volume is 0 048 against 0 053 formerly The former work indicates by extrapolation that a transition from III to VIII should run at room temperature in the neighborhood of 13,000. No evidence for this was found in the present work, the transition apparently being totally suppressed by sluggishness at the low temperature. This means that the compression data given in the table above the transition pressure pertain to the modification III The data would indicate a drop of compressibility to nearly one half on passing from II to III

Ammonium perborate has not been previously measured I owe it to the courtesy of Dr Hans Jaffe of the Brush Development Co It was provided in single crystal form, and had been produced as part of the war time program of investigation of all possible piezo-electric crystals My intention was to measure it in my program of linear compressibility measurements up to 30,000 Discovery of transitions, however, made it impossible to use for this purpose This substance in all probability has two transitions instead of the one shown in the table Below 5,000 there is probably a small transition with volume discontinuity of the order of one seventh of that given in the table at higher pressures. Both transitions are sluggish. The volume discontinuity associated with the transition at 23,000 is probably too small and the compressibility immediately above the transition too high. The data as given in the table indicate a jump up of compressibility on passing to higher pressures through the transition, and an abnormally rapid dropping of the compressibility of the high pressure phase with increasing pressure.

Potassium pentaborate, like ammonium pentaborate, has not been previously measured. It was obtained from the same source, for the same purpose, and like it had to be discarded for measurement of the linear compressibility because of transitions. It also has two transitions, but inversely situated as compared with ammonium pentaborate. Here the larger transition is at the low pressure, and one with volume discontinuity only one seventh as large at the high pressure The sluggishness is not as great as for the ammonium salt. At the high pressure transition there is no appreciable discontinuity of compressibility There may be a slight upward jump in compressibility on passing to the high pressure form at 3,540, although this is not certain

Dextrose sodium iodide I owe to the courtesy of Dr S O Morgan of the Bell Telephone Laboratories It was single crystal stock, destined for measurement of the linear compressibility in the 30,000 apparatus. Two transitions were found, both above 30,000, so that it was possible to measure the linear compressibility over the entire range up to 30,000 in addition to the present measurements of volume compression to 40,000. Reference is made to a following paper for the details of the linear compressions in different directions The volume compression at 30,000 calculated from the linear compressions was 0 1183 against 0 1196 found now.

The $MgSO_4 \cdot 7H_2O$ I owe to the kindness of Mr George C Kennedey, who grew it from aqueous solution by the method of slowly-lowering temperature It was destined for measurements of the linear compression up to 30,000, but the discovery of the complicated system of transitions indicated in the table prevented measurements of linear compression above 10,000 At 10,000 the volume compression calculated from the linear compressions was 0 0408 against 0 0445 given in the table It is probable that the lower value is more accurate, the present measurements being obscured by the sluggish transition

Miscellaneous Compounds Compounds 1 to 8 in Table VI were obtained from the Eastman Kodak Co., from their commercial stock Of these numbers 1 to 5 were tried because they have multiple carbon bonds, and it was thought that there was some possibility that such compounds might suffer irreversible transitions at sufficiently high pressures similar to that found in CS_2. None was found, however. I owe the suggestion of which compounds of this nature would be most feasible to try to Dr Linus Pauling.

Compounds 9 to 25 were single crystal stock, destined to be used in the measurements of linear compression to 30,000 Full details about the origins of this material will be found in a paper to follow this Comment here is required on only two of these materials. $NiSO_4 \cdot 6H_2O$ has a very marked transition of the second kind in the direction perpendicular to the axis in the neigh-

TABLE VI

VOLUME DECREMENTS OF MISCELLANEOUS COMPOUNDS

Pressure kg/cm²	1 Mela-mine	2 Cyana-mide	3 Di Cyana-mide	4 Hexa-methylene-tetramine	5 Oxalic Acid anhydrous	6 2–4-Dichloro-phenol	7 Iodoform	8 Urea Nitrate	9 Ammo-nium Phosphate	10 Potas-sium Phosphate	11 Sulfamic Acid	12 Li Na_3 Cr_4O_7 $6H_2O$	13 $NaClO_3$
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
5 000	0376	0357	0340	0433	0357	0549	0549	0372	0177	0179	0207	0172	0185
10 000	0618	0615	0589	0739	0620	0893	0921	0642	0332	0335	0378	0345	0349
15 000	0811	0832	0796	0976	0835	1149	1194	0855	0471	0474	0524	0490	0491
20,000	0975	1019	0976	1167	1010	1358	1414	1034	0595	0599	0654	0620	0616
25 000	1116	1184	1138	1330	1161	1533	1599	1191	0709	0713	0775	0753	0736
30,000	1242	1334	1285	1474	1296	1687	1759	1331	0815	0817	0885	0883	0854
35,000	1358	1471	1421	1599	1421	1823	1902	1456	0914	0912	0970	0995	0952
40,000	1469	1600	1547	1708	1538	1945	2034	1569	1006	0996	1050	1083	1031

TABLE VI (Continued)

VOLUME DECREMENTS OF MISCELLANEOUS COMPOUNDS

Pressure kg/cm²	14 Rochelle Salt	15 Potassium Alum	16 $NiSO_4$ $6H_2O$	17 Sodium Am-monium Tartrate	18 Rubidium Tartrate	19 Morpholine Hydrogen Tartrate	20 Ammoni-um Di-hydrogen Phosphate	21 Ethylene Diamine Tartrate	22 Dextrose Sodium Chloride	23 HCO_3	24 Benzil	25 Strontium Formate
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
5,000	0235	0282	0174	0271	0234	0333	0170	0290	0266	0264	0605	0180
10,000	0439	0514	0349	0498	0435	0596	0322	0523	0490	0459	0961	0344
15,000	0616	0704	0477	0692	0607	0812	0459	0718	0684	0625	1243	0491
20,000	0770	0869	0596	0863	0758	0995	0585	0886	0861	0770	1480	0621
25,000	0920	1020	0739	1014	0894	1155	0700	1033	1025	0898	1676	0741
30,000	1053	1157	0870	1148	1014	1298	0806	1161	1178	1015	1838	0856
35,000	1167	1281	0979	1267	1120	1424	0904	1273	1320	1123	1978	0958
40 000	1262	1393	1070	1372	1214	1536	0999	1372	1452	1225	2102	1052

borhood of 20,000, the compressibility increasing abruptly at this pressure The same anomaly is shown also by the volume measurements of Table VI, but quantitatively it is not nearly as large as would be demanded by the length measurements. It would appear that this anomaly does not become fully developed when the stress is not truly hydrostatic The second material is benzil, which showed a complicated system of anomalies for the length measurements, but no trace of them in the volume measurements of Table VI. Again, part at least of the anomaly would seem to be suppressed by comparatively light constraint

Compounds with Ortho-, Meta-, and Para- Forms A study was made of a large number of compounds of this class to find whether there is any systematic variation in compressibility The compounds were selected from the catalogue of the Eastman Kodak Co, all the groups for which the three forms were listed and for which all three are solid under ordinary conditions The results are collected in Table VII There are a few groups for which only two forms are tabulated, in these groups three forms had been listed and ordered but one of the forms proved to be out of stock The purity is that usual to chemicals of this nature, and is indicated in the catalogue In a few cases grades of "technical" or "practical" purity only were available, these are indicated in the following As furnishing some clue to the character of the material, the densities at atmospheric pressure and room temperature are also recorded in the table These densities were obtained incidentally in the course of the measurements from the weight and the absolute dimensions at atmospheric pressure of the charge when mounted in the piezometer

The arrangement in the table is a sort of hybrid alphabetical arrangement, according to the most important part of the molecule.

Of the compounds, o- and m- amino phenol were listed as "practical" grade, and m-phenylene diamine as "technical." The m-chloroacetanilide was marked on the bottle "to contain 5 per cent of an aromatic amine", the di-m-cresyl carbonate contained an appreciable quantity of some sort of moisture which squeezed out when the pellet for the piezometer was formed, and the tri-m-cresyl thiophosphate, contained so much visible moisture that it did not seem worth while to measure it. It should be noticed incidentally that the para form of the sodium-xylene-sulfonate is not similar in structure to the other two,

TABLE VII

COMPRESSIONS OF ORTHO- META- AND PARA- COMPOUNDS

	1			2			3			4		5			6			7		
Pressure kg/cm²	Chloroacetanilide C_8H_8ONCl			Nitro-aniline $C_6H_6O_2N_2$			Diphenyl Benzene $C_{18}H_{14}$			Nitro-chloro-benzene $C_6H_4O_2NCl$		Nitro-bromo-benzene $C_6H_4O_2NBr$			Nitro-iodo-benzene $C_6H_4O_2NI$			Amino-Benzoic Acid $C_7H_7O_2N$		
	o	m	p	o	m	p	o	m	p	o	p	o	m	p	o	m	p	o	m	p
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
2,500	0347	0311	0259	0228	0240	0255	0339	0294	0314	0333	0328	0320	0253	0266	0310	0288	0271	0265	0160	0271
5,000	0610	0572	0477	0421	0438	0457	0609	0536	0561	(a) 0673	0584	0556 (b)	0456	0488	0544	0489	0493	0479	0292	0483
10,000	0998	0971	0822	0729	0748	0772	1012	0918	0934	1113	0963	0991	0774	0843	0893	0825	0835	0814	0503	0808
15,000	1297	1261	1084	0964	0991	1015	1303	1199	1195	1386	1237	1292	1018	1105	1152	1077	1087	1064	0671	1058
20,000	1540	1490	1292	1149	1190	1217	1526	1414	1394	1591	1455	1513	1214	1312	1355	1276	1290	1267	0809	1262
25,000	1740	1678	1463	1305	1357	1385	1708	1591	1557	1752	1633	1687	1377	1487	1522	1438	1460	1433	0928	1431
30,000	1901	1832	1603	1439	1498	1532	1856	1739	1698	1890	1785	1833	1517	1638	1664	1577	1607	1573	1034	1578
35,000	2034	1960	1714	1559	1620	1662	1982	1865	1823	2005	1916	1956	1637	1770	1797	1699	1733	1691	1130	1707
40,000	2144	2066	1803	1669	1733	1777	2091	1973	1937	2107	2031	2061	1741	1887	1916	1811	1846	1793	1221	1821
Atmospheric Density	1 349	1 337	1 335	1 465	1 434	1 446	1 171	1 195	1 247	1 558	1 512	1 943	1 982	1 952	2 304	2 171	2 198	1 346	1 526	1 371

(a) Transition at 4,030 Compressions 0484 and 0550 (b) Transition at 7 490 Compressions 0741 and 0795

TABLE VII (Continued)

COMPRESSIONS OF ORTHO-, META- AND PARA- COMPOUNDS

Pressure kg/cm²	8 Chloro-Benzoic Acid $C_7H_5O_2Cl$			9 Bromo-Benzoic Acid $C_7H_5O_2Br$			10 Iodo-Benzoic Acid $C_7H_5O_2I$			11 Methyl- — -Nitro-cinnamate $C_{10}H_9O_4N$			12 Di- — -cresyl carbonate $C_{15}H_{14}O_3$			13 Amino Phenol C_6H_7ON			14 Nitro-Phenol $C_6H_5O_3N$		
	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p	o	m	p
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
2,500	0275	0288	0273	0266	0308	0263	0275	0266	0257	0301	0290	0273	0365	0340	0312	0267	0239	0236	0317	0258	0271
5,000	0494	0514	0494	0482	0544	0473	0495	0487	0471	0532	0512	0492	0623	0606	0553	0467	0429	0423	0563	0462	0488
10 000	0829	0862	0832	0812	0914	0804	0824	0834	0819	0887	0855	0836	1007	0991	0913	0774	0728	0725	0935	0780	0834
15,000	1084	1124	1088	1061	1190	1053	1066	1093	1082	1148	1117	1096	1286	1267	1174	1016	0955	0965	1211	1024	1095
20,000	1288	1330	1293	1261	1408	1257	1266	1302	1290	1358	1327	1305	1504	1483	1380	1209	1137	1159	1419	1222	1304
25,000	1456	1502	1465	1431	1588	1430	1430	1474	1465	1532	1504	1477	1676	1663	1551	1364	1287	1323	1589	1385	1474
30 000	1599	1646	1612	1577	1739	1577	1568	1623	1616	1682	1655	1625	1816	1814	1692	1493	1413	1465	1728	1525	1621
35,000	1728	1776	1741	1706	1869	1706	1688	1750	1749	1813	1785	1755	1932	1945	1811	1604	1521	1590	1846	1646	1748
40 000	1848	1897	1856	1822	1980	1823	1800	1857	1864	1938	1903	1870	2031	2060	1911	1703	1613	1705	1947	1750	1861
Atmospheric Density	1 530	1 516	1 511	1 916	1 840	1 871	2 211	2 138	2 173	1 401	1 396	1 416	1 243	1 284	1 265	1 279	1 255	1 287	1 481	1 476	1 468

TABLE VII (Continued)

COMPRESSIONS OF ORTHO-, META- AND PARA- COMPOUNDS

Pressure kg/cm²	15 Phenylene-diamine $C_6H_8N_2$			16 Phenylene-diamine Hydrochloride $C_6H_{10}N_2Cl$			17 Amino Benzene Sulfonic Acid $C_6H_7O_3NS$			18 Sodium- — -Xylene Sulfonate $C_8H_{11}O_4SNa$			19 Tri- — -Cresyl Thio-phosphate $C_{21}H_{21}O_4P$		20 Toluic Acid $C_8H_8O_2$			21 Acetyl- — -Toluidine $C_9H_{11}ON$			22 Toluidine Hydrochloride $C_7H_{10}NCl$		
	o	m	p	o	m	p	o	m	p	o	m	p·1H₂O	o	p	o	m	p	o	m	p	o	m	p
0	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000	0000
2,500	0255	0253	0267	0183	0227	0153	0221	0188	0197	0206	0236	0195	0320	0364	0329	0305	0328	0284	0324	0280	0240	0328	0229
5,000	0468	0465	0482	0340	0403	0281	0402	0323	(c) 0544	0391	0440	0354	0563	0643	0583	0539	0588	0519	0582	0503	0416	0588	(e) 0774
10,000	0809	0797	0811	0601	0673	0493	0683	0523	0958	0706	0775	0609	0929	1041	0945	0896	0975	0874	0995	0843	0684	0976	1073
15,000	1070	1053	1061	0835	0893	0669	0898	0676	(d) 1320	0959	1029	0814	1196	1333	1216	1168	1255	1134	1308	1097	0899	1261	1288
20 000	1279	1253	1257	1050	1080	0824	1076	0798	1563	1165	1229	0987	1410	1558	1430	1387	1476	1341	1550	1298	1075	1485	1460
25,000	1450	1412	1417	1237	1246	0959	1223	0902	1736	1342	1390	1137	1587	1741	1609	1567	1664	1509	1743	1458	1226	1668	1608
30,000	1596	1544	1555	1399	1394	1079	1356	0997	1868	1492	1524	1261	1739	1895	1763	1725	1825	1653	1899	1599	1359	1817	1741
35,000	1720	1656	1675	1536	1523	1186	1473	1087	1979	1617	1638	1369	1874	2025	1900	1861	1962	1783	2032	1722	1479	1946	1861
40,000	1825	1756	1779	1648	1634	1284	1578	1172	2076	1722	1737	1467	1998	2137	2023	1976	2079	1897	2147	1829	1587	2065	1972
Atmospheric Density	1 229	1 223	1259	1 424	1 378	1 493	1 617	1 668	1 478	1 476	1 492	1 498	1 293	1 419	1 309	1 232	1 296	1 162	1 138	1 169	1 247	1 216	1 191

(c) Transition at 3,980 Compressions 0270 and 0376
(d) Transition at 11,440 Compressions 1058 and 1082
(e) Transition at 2 550 Compressions 0234 and 0551

but contains one molecule of water of crystallization

There is a great range in the mechanical properties of these compounds, and these properties might well be studied for their own sake. Most of the compounds form smooth and compact pellets when subjected to the preliminary pressure of the order of 15,000 kg/cm^2, but there are a few exceptions in which the pellet is extremely friable and difficult to handle. Notably in this class were the three sodium-xylene-sulfonates. The pellet in these cases can be made coherent enough to get into the piezometer by greasing the mold in which it is formed with a minimum amount of a mixture of vaseline and colloidal graphite. Sometimes merely rubbing the internal wall of the steel mold with graphite was sufficient.

In general the mechanical strength of these compounds is so low that one can expect the effect of the initial configuration, whether as powder or flakes or granules, to vanish from the final measurements, which should give very closely the true cubic compression of single crystal material under hydrostatic pressure. Direct check was made of this for o-chloro benzoic acid, which showed no significant difference between a pellet formed by fusing and turning to shape and a pellet formed in the regular way by compression of the dry powder.

Certain features of the behavior of various of the substances require detailed comment. There is an increase of compressibility of about 30 per cent on passing through the transition of o-nitrobenzene from the low to the high pressure form. There is an increase of compressibility of 65 per cent on passing from the low to the high pressure form of o-nitrochlorobenzene, and the compressibility of the latter form decreases abnormally rapidly with increasing pressure immediately above the transition point. There is an enormous increase of compressibility on passing to the high pressure form at the low pressure transition of p-amino-benzene sulfonic acid, the exact magnitude of which is difficult to estimate because of the low pressure range of stability of the low form. The second form drops rapidly in compressibility with increasing pressure above the transition. At the second transition the compressibility also jumps up on passing to the high pressure form. This substance is one which exhibited extreme friability and friction in the formation of the pellet, there may well have been a connection with the low pressure transition. The transition listed for p-toluidine hydrochloride was unusually sluggish and ran perceptibly over a pressure range of 20,000 kg/cm^2 with increasing pressure, and the reverse transition with decreasing pressure required an unusually long time for completion at atmospheric pressure. The compressions in the first 20,000 kg/cm^2 cannot be expected to be very accurate, but may be expected to be obscured by transition effects. The data given in the table for o-phenylene diamine hydrochloride are smoothed so as to completely ignore a small initial episode at low pressures in some respects like a transition, but largely irreversible. It is also to be noticed that the compressibility of this substance decreases linearly with pressure above 20,000, instead of at a continually retarded rate, as for most all other substances in the table. Finally, m-phenylene-diamine was the only substance which during compression exhibited any effects indicative of friction or failure of approximate hydrostatic pressure. This snapped twice audibly on increase of pressure, and at one point there was a slight discontinuity in piston displacement. The behavior on release of pressure was normal. This material is unusually glass-like and brittle.

In order to give a general idea of the nature of the results for these compounds, the compressions at the top pressure, 40,000, are plotted in Figure 1 for the different members of the various series of compounds, including in the compressions the transitions in the five cases in which they occur. It is evident at a glance that there is no systematic effect of the o-, m-, p- structure on compression, although there are many instances where the differences of compression between the different forms are large. Statistically, the ortho form is the most compressible of the three in 9 cases, and least compressible in 6, the meta form is most compressible in 6 and least compressible in 8 cases, and the para form most compressible in 7 and least compressible in 8 cases. Considering the small number of examples this distribution must be judged to be completely random. The abnormally small compression of the meta forms of amino-benzoic acid and amino-benzene sulfonic acid is to be commented on. In view of the very large variations in these two series it must be recognized that on occasion other factors than o-, m-, or p- position may be much more potent in determining compressibility. It would be rewarding to make an X-ray analysis of these two amino compounds to find whether there is anything unusual about the crystal structure.

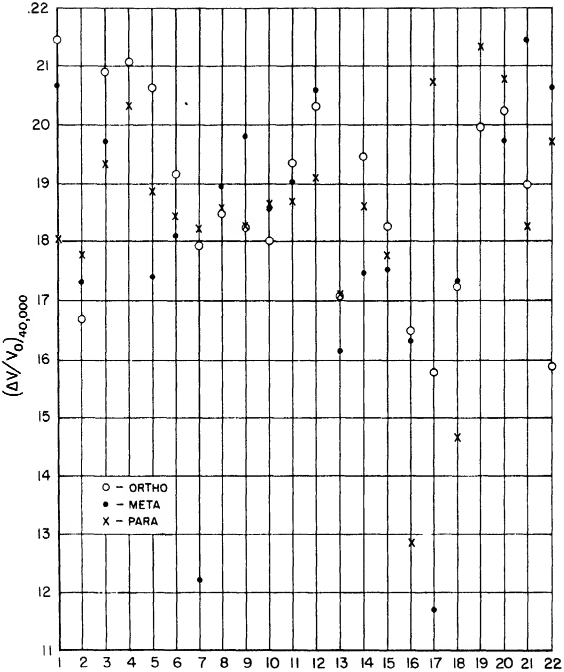

FIGURE 1 The relative compressions at 40,000 kg cm[2] of the various series of o-, m-, and p- compounds as numbered in Table VII

Other things being equal, it is to be expected that the compressions in any single series of compounds will be in the inverse order of the densities at atmospheric pressure In order to see to what extent the density controls, I have compared the order of the inverse compressions with that of the atmospheric densities for all 22 series of compounds, and find the same order for the two properties in only 5 of the 22 instances This is hardly more than would be expected by pure chance, so that the conclusion may be drawn that the connection is not immediate and unique between density and compression There is however, a recognizable statistical connection If one plots the product of atmospheric density and relative compression at 40,000 instead of merely relative compression at 40,000 in a diagram analogous to figure 1, it will be found that the three points for any one series have an obvious tendency to bunch much more closely than in figure 1

It might perhaps be expected that at pressures as high as 40,000 any specific effects of structure might tend to be wiped out, leaving outstanding the contribution to the compression of the atoms themselves In this case, one might expect some approach to an additive law of compression in terms of atomic constitution In order to facilitate examination of this question the gross overall atomic formulas of the various compounds have been given in Table VII. I have not, however, been able to find any significant correlation, suggesting the conclusion that the intrinsic compressibility of the atoms entering into these compounds differs so little that any effect of them is obscured by other factors It might be mentioned, however, that the two series differing only by the substitution of one halogen for another, namely the series 4, 5, 6 and 8, 9, 10 of the table, do show the same progression of values in the product of atmospheric density and compression at 40,000, a progression not shown by the compressions themselves The variation of the product within any single series is, furthermore, comparatively minor

The shape of the curves of volume decrement against pressure is in general the same for the three members of a series There are, however, several examples of crossing of the curves, which means a different variation of compressibility with pressure for the different forms. Among the most pronounced of these instances are m- and p- diphenyl benzene, o- and p- phenylene diamine, and o- and m- phenylene diamine hydrochloride The apparent example of o- and m-dicresyl carbonate is uncertain, because of probable impurity of the m- form, a perceptible amount of liquid having been squeezed out on formation of the pellet

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46	Subrahmanyan Chandrasekhar	Williams Bay, Wis
13	Julian Lowell Coolidge	Cambridge
15	Leonard Eugene Dickson	Chicago, Ill
33	Jesse Douglas	Brooklyn, N Y
38	John Charles Duncan	Wellesley
34	Griffith Conrad Evans	Berkeley, Cal
30	Philip Franklin	Belmont
32	Einar Hille	New Haven, Conn
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38	E[lvin] Morton Jellinek	New Haven, Conn
15	Carl Otto Lampland	Flagstaff, Ariz
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25	Willem Jacob Luyten	Minneapolis, Minn
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19	Forest Ray Moulton	Washington, D C
44	John von Neumann	Princeton, N J
43	Cecilia Payne-Gaposchkin	Lexington
18	Henry Bayard Phillips	Lincoln
96	Charles Lane Poor	New York, N Y
14	Roland George Dwight Richardson	Providence, R I
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09	Vesto Melvin Slipher	Flagstaff, Ariz
19	Virgil Snyder	Ithaca, N Y
21	Joel Stebbins	Madison, Wis
27	Harlan True Stetson	Needham
30	Dirk Jan Struik	Belmont
42	Otto Struve	Williams Bay, Wis
23	Oswald Veblen	Princeton, N J
29	Joseph Leonard Walsh	Cambridge
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28	Adelbert Ames, Jr	Hanover, N H
37	Kenneth Tompkins Bainbridge	Cambridge
21	Samuel Jackson Barnett	Pasadena, Cal
12	Francis Birch	Cambridge
12	Percy Williams Bridgman	Cambridge
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34	Franzo Hazlett Crawford	Williamstown
13	Henry Crew	Evanston, Ill
11	Harvey Nathaniel Davis	Hoboken, N J
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12	Arthur Louis Day	Bethesda, Md
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01	Alexander Wilmer Duff	Worcester

45	Robley Dunglison Evans	Belmont
09	Arthur Woolsey Ewell	Worcester
39	Harry Edward Farnsworth	Providence, R I
43	Philipp Frank	Cambridge
97	Harry Manley Goodwin	Brookline
29	Arthur Cobb Hardy	Wellesley
31	George Russell Harrison	Belmont
14	John Charles Hubbard	Washington, D C
17	Gordon Ferrie Hull	Hanover, N H
40	Frederick Vinton Hunt	Belmont
22	Edwin Crawford Kemble	Cambridge
44	Ronold Wyeth Percival King	Winchester
43	Edwin Herbert Land	Cambridge
37	Ernest Orlando Lawrence	Berkeley, Cal
31	Robert Bruce Lindsay	Providence, R I
01	Theodore Lyman	Brookline
34	Louis Williams McKeehan	Washington, D C
14	Ernest George Merritt	Ithaca, N Y
14	Robert Andrews Millikan	Pasadena, Cal
34	Harry Rowe Mimno	Lexington
34	Philip McCord Morse	Bayport, N Y
31	Otto Oldenberg	Cambridge
40	J Robert Oppenheimer	Princeton, N J
34	Leigh Page	New Haven, Conn
07	George Washington Pierce	Cambridge
41	Isidor Isaac Rabi	New York, N Y
27	John Clarke Slater	Cambridge
37	George Walter Stewart	Iowa City, Ia
43	Donald Charles Stockbarger	Belmont
46	Julius Adams Stratton	Belmont
37	Jabez Curry Street	Belmont
12	Maurice deKay Thompson	Newark, N J
28	Manuel Sandoval Vallarta	Mexico, D F
35	Robert Jemison Van de Graaff	Belmont
34	John Hasbrouck Van Vleck	Cambridge
35	Bertram Eugene Warren	Arlington
18	David Locke Webster	Palo Alto, Cal
11	Edwin Bidwell Wilson	Brookline
13	Robert Williams Wood	Baltimore, Md
17	John Zeleny	New Haven, Conn

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26	Roger Adams	Urbana, Ill
44	Isadore Amdur	Cambridge
45	Eric Glendinning Ball	Newton Highlands
13	Wilder Dwight Bancroft	Ithaca, N Y
46	Paul Doughty Bartlett	Weston
07	Gregory Paul Baxter	Cambridge
29	James Alexander Beattie	Belmont
19	Arthur Alphonzo Blanchard	Brookline
14	Marston Taylor Bogert	New York, N Y
36	Harold Simmons Booth	Cleveland, O
38	Emile Monnin Chamot	Ithaca, N Y
42	Samuel Cornette Collins	Belmont
24	James Bryant Conant	Cambridge
45	Arthur Clay Cope	Belmont
47	Paul Clifford Cross	Providence, R I
23	Tenney Lombard Davis	Norwell
37	John Tileston Edsall	Dedham
37	Gustavus John Esselen	Swampscott
40	William Lloyd Evans	Columbus, O
33	Louis Frederick Fieser	Belmont
15	George Shannon Forbes	Cambridge
35	Louis Harris	Belmont
36	Albert Baird Hastings	Brookline
38	Robert Casad Hockett	Concord
36	Ernest Hamlin Huntress	Melrose Highlands
19	Frederick George Keyes	Cambridge
33	George Bogdan Kistiakowsky	Cambridge
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14	Arthur Becket Lamb	Brookline
18	Irving Langmuir	Schenectady, N Y
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32	Kenneth Lamartine Mark	Boston
41	Charles Edward Kenneth Mees	Rochester, N Y
35	Nicholas Athanasius Milas	Belmont
36	Avery Adrian Morton	Watertown
19	Edward Mueller	Cambridge
31	William Albert Noyes, Jr	Rochester, N Y
45	John Lawrence Oncley	Watertown
44	Linus Carl Pauling	Pasadena, Cal
39	Clifford Burrough Purves	Montreal, Can
14	Martin André Rosanoff	Mt Lebanon, Pa
28	George Scatchard	Cambridge
32	Walter Cecil Schumb	East Milton
15	Miles Standish Sherrill	Cambridge
20	Harry Monmouth Smith	Brookline
34	Leighton Bruerton Smith	Beverly
47	Clark Conkling Stephenson	Cambridge
46	Walter Hugo Stockmayer	Weston
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22	Richard Chace Tolman	Pasadena, Cal
38	Harold Clayton Urey	Chicago, Ill
41	Harry Boyer Weiser	Houston, Tex
11	Willis Rodney Whitney	Schenectady, N Y
19	Robert Seaton Williams	Belmont
44	Edgar Bright Wilson, Jr	Cambridge
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45	Hardy Cross	New Haven, Conn
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43	Bradley Dewey	Cambridge
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41	Charles Stark Draper	Newton
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21	William Frederick Durand	Palo Alto, Cal
46	Howard Wilson Emmons	Sudbury
27	Gordon Maskew Fair	Cambridge
32	Glennon Gilboy	Lincoln
32	Albert Haertlein	Watertown

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44 Arthur Robert von Hippel Weston
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34 Jerome Clarke Hunsaker Boston
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11 Dugald Caleb Jackson Cambridge
30 Frank Baldwin Jewett Short Hills, N J
01 Lewis Jerome Johnson Cambridge
37 Joseph Henry Keenan Belmont
32 Ralph Restieaux Lawrence Belmont
23 William Henry Lawrence Jamaica Plain
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39 C Richard Soderberg Weston
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[28] 44 Karl Terzaghi Winchester
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40 John Wulff Cambridge
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15 Wallace Walter Atwood Worcester
41 Alan Mara Bateman New Haven, Conn
46 Roland Frank Beers Lincoln
38 Marland Pratt Billings Wellesley
21 Norman Levi Bowen Chicago, Ill
16 Isaiah Bowman Baltimore, Md
33 Charles Franklin Brooks Milton
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34 Sterling Price Fergusson Milton
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14 Louis Caryl Graton Cambridge
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21 William Jackson Humphreys Washington, D C
46 Cornelius Searle Hurlbut, Jr Belmont
44 Columbus O'Donnell Iselin Woods Hole
95 Robert Tracy Jackson Peterborough, N. H
02 Thomas Augustus Jaggar Honolulu, T H
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00 Liberty Hyde Bailey Ithaca, N Y
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45 Herman Augustus Spoehr Palo Alto, Cal
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22 William Henry Weston, Jr Winchester
32 Ralph Hartley Wetmore Cambridge

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28 Roy Graham Hoskins — Waban
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45 Leland Clifton Wyman — Jamaica Plain
15 Robert Mearns Yerkes — New Haven, Conn

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47 Arthur Wilburn Allen — Brookline
32 Joseph Charles Aub — Belmont
36 Oswald Theodore Avery — New York, N Y
29 James Bourne Ayer — Milton
(28) 32 Franklin Greene Balch — Boston
41 Walter Bauer — Waban
47 David Lawrence Belding — Boston
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28 Warfield Theobald Longcope — Baltimore, Md
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14 Frederick Herman Verhoeff Brookline
47 Shields Warren West Newton
27 Joseph Treloar Wearn Cleveland, O
40 Paul Dudley White Brookline
12 Simeon Burt Wolbach South Sudbury

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(24) 32 Francis Noyes Balch Jamaica Plain
38 Henry Moore Bates Ann Arbor, Mich
36 Stoughton Bell Cambridge
33 Harry Augustus Bigelow Chicago, Ill
36 Claude Raymond Branch Providence, R I
33 John Dickinson Philadelphia, Pa
38 Robert Gray Dodge Boston
31 Fred Tarbell Field Newton
40 Lon Louvois Fuller Cambridge
39 Herbert Funk Goodrich Philadelphia, Pa
33 Theodore Francis Green Providence, R I
38 Frank Washburn Grinnell Boston
41 Erwin Nathaniel Griswold Belmont
39 John Loomer Hall Boston
39 Augustus Noble Hand New York, N Y
33 Learned Hand New York, N Y
39 Albert James Harno Urbana, Ill
47 Mark DeWolfe Howe Cambridge
18 Charles Evans Hughes Washington, D C
38 Melvin Maynard Johnson Brookline
38 James McCauley Landis Washington, D C
32 Sayre Macneil Pasadena, Cal
32 Calvert Magruder Cambridge
31 William DeWitt Mitchell New York, N Y
31 Edmund Morris Morgan Arlington
47 John Lord O'Brian Washington, D C
36 Henry Parkman, Jr Boston
39 Robert Porter Patterson New York, N Y
01 George Wharton Pepper Philadelphia, Pa
11 Roscoe Pound Watertown
36 Stanley Elroy Qua Lowell
32 Francis Bowes Sayre Washington, D C
21 Austin Wakeman Scott Cambridge
36 Sidney Post Simpson Cambridge
39 Thomas Walter Swan New York, N Y
32 Edward Sampson Thurston San Francisco, Cal
43 Charles Edward Wyzanski, Jr Cambridge

CLASS III, SECTION II—*Government, International Law, and Diplomacy*—30

36 Howard Landis Bevis Columbus, O
33 Edwin Montefiore Borchard New Haven, Conn
46 Harvey Hollister Bundy Bosotn
40 Robert Granville Caldwell Belmont
32 William Richards Castle, Jr Washington, D C
32 Joseph Perkins Chamberlain New York, N Y
33 Robert Treat Crane New York, N Y
35 Tyler Dennett Hague, N Y
46 John Sloan Dickey Hanover, N H
27 William Cameron Forbes Norwood
44 Carl Joachim Friedrich Concord
34 Edgar Stephenson Furniss New Haven, Conn
32 Joseph Clark Grew Washington, D C
35 Charles Grove Haines Los Angeles, Cal
41 Hajo Holborn Hamden, Conn
27 Arthur Norman Holcombe Cambridge
32 Philip Carryl Jessup New York, N Y
32 Charles Edward Merriam Chicago, Ill
13 William Bennett Munro Pasadena, Cal
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41 Gaetano Salvemini Cambridge
46 Robert Burgess Stewart Winchester
40 Thomas Head Thomas Cambridge
44 Sarah Wambaugh Cambridge
17 Sumner Welles Oxon Hill, Md
43 Payson Sibley Wild Jr Cambridge
32 William Franklin Willoughby Washington, D C
14 George Grafton Wilson Grafton, Vt
27 Quincy Wright Chicago, Ill
33 Henry Aaron Yeomans Harvard

CLASS III, SECTION III *Economics and Sociology*—58

36 James Waterhouse Angell New York, N Y
17 George Pierce Baker Boston
36 James Cummings Bonbright New York, N Y
43 Augusta Fox Bronner (Mrs William Healy) Boston
44 Douglass Vincent Brown Brookline
46 Theodore Henry Brown Cambridge
33 Harold Hitchings Burbank Cambridge
34 John Maurice Clark Westport, Conn
28 Arthur Harrison Cole Cambridge
21 Clive Day New Haven, Conn
32 Arthur Stone Dewing Newton
41 Carl Rupp Doering Cambridge
32 Wallace Brett Donham Cambridge
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45 Edwin Sharp Burdell — New York, N Y
41 Godfrey Lowell Cabot — Boston
47 Thomas Dudley Cabot — Weston
47 William Henry Claflin, Jr — Belmont
43 Ada Louise Comstock (Mrs Wallace Notestein), — New Haven Conn
42 Donald Kirk David — Boston
38 Edmund Ezra Day — Ithaca, N Y
32 Henry Sturgis Dennison — Framingham
46 David Frank Edwards — Cambridge
(28) 32 William Lusk Webster Field — Milton
39 Ralph Edward Flanders — Springfield, Vt
38 Horace Sayford Ford — Belmont
44 Raymond Blaine Fosdick — New York, N Y
35 Jerome Davis Greene — Cambridge
(28) 32 Edward Jackson Holmes — Topsfield
44 Ernest Martin Hopkins — Hanover, N H
34 Henry Plimpton Kendall — Sharon
44 James Rhyne Killian, Jr — Wellesley Hills
32 Thomas William Lamont — New York, N Y
39 Morris Evans Leeds — Philadelphia, Pa
34 Clarence Cook Little — Bar Harbor, Me
47 Ralph Lowell — Westwood
36 Dumas Malone — New York, N Y
42 Daniel L Marsh — Boston
45 Keyes DeWitt Metcalf — Belmont
45 Henry Allen Moe — New York, N. Y
02 Herbert Putnam — Washington, D C
44 Beardsley Ruml — New York, N. Y.
34 Erwin Haskell Schell — Cambridge
38 Charles Seymour — New Haven, Conn
35 Henry Lee Shattuck — Boston
37 Henry Southworth Shaw — Melrose
(28) 32 Payson Smith — Orono, Me
46 Huntley Nowell Spaulding — Rochester, N H
33 Albert Warren Stearns — Billerica
(24) 32 Edwin Sibley Webster — Brookline
44 Charles Edward Wilson — New York, N Y
41 Laurence Leathe Winship — South Sudbury
(25) 32 Benjamin Loring Young — Weston
39 Owen D Young — New York, N Y

CLASS IV—The Humanities—175

Section I *Theology, Philosophy, and Psychology*—40

32 Michael Joseph Ahern — Weston
32 James Rowland Angell — Hamden, Conn
33 John Gilbert Beebe-Center — Swampscott
38 Julius Seelye Bixler — Waterville, Me
46 Brand Blanshard — New Haven, Conn
24 Edwin Garrigues Boring — Cambridge
28 Edgar Sheffield Brightman — Newton
31 Henry Addington Bruce — Cambridge
32 Leonard Carmichael — Tufts College
36 Robert Pierce Casey — Providence, R I
33 Curt John Ducasse — Providence, R I
43 Angus Dun — Washington, D C
38 James Everett Frame — Princeton, N J
37 Clarence Henry Graham — New York, N Y
45 Edwin Ray Guthrie — Seattle, Wash
30 William Henry Paine Hatch — Cambridge
32 William Healy — Natick
35 Clark Leonard Hull — New Haven, Conn
28 Albert Cornelius Knudson — Cambridge
32 Karl Spencer Lashley — Orange Park, Fla
29 Clarence Irving Lewis — Lexington
42 Richard Peter McKeon — Chicago, Ill
35 Henry Alexander Murray, Jr — Boston
47 Norman Burdett Nash — Boston
32 Arthur Darby Nock — Cambridge
28 Johnson O'Connor — Boston
17 Charles Edwards Park — Boston
33 Carroll Cornelius Pratt — Princeton, N J
31 Henry Knox Sherrill — New York, N Y
27 Willard Learoyd Sperry — Cambridge
29 Russell Henry Stafford — Hartford, Conn
46 Stanley Smith Stevens — Cambridge
45 Charles Lincoln Taylor, Jr — Cambridge
34 Lewis Madison Terman — Palo Alto, Cal
34 Edward Lee Thorndike — Montrose, N Y
37 Louis Leon Thurstone — Chicago, Ill
28 Henry Bradford Washburn — Cambridge
17 John Broadus Watson — New York, N Y
33 Frederic Lyman Wells — Newton Highlands
35 Robert Sessions Woodworth — New York, N Y

CLASS IV, SECTION II—*History, Archaeology, and Anthropology*—35

41 Warren Ortman Ault — Waban
28 James Phinney Baxter, 3d — Williamstown
47 Ruth Fulton Benedict — New York, N Y
27 Robert Pierpont Blake — Cambridge
46 Clarence Saunders Brigham — Worcester
39 Crane Brinton — Cambridge
(25) 32 William Brooks Cabot — Boston
42 Henry Joel Cadbury — Cambridge
34 Clarence Gordon Campbell — New York, N Y
43 Carleton Stevens Coon — Cambridge
44 William Bell Dinsmoor — New York, N Y
38 Claude Moore Fuess — Andover
43 Hugh O'Neill Hencken — Chestnut Hill
14 Bert Hodge Hill — Athens, Greece
27 Earnest Albert Hooton — Cambridge
33 Halford Lancaster Hoskins — Washington, D C
47 Wilbur Kitchener Jordan — Cambridge
44 Clyde Kay Maben Kluckhohn — Cambridge
12 Alfred Louis Kroeber — Berkeley, Cal
44 Ambrose Lansing — New York, N Y
32 Waldo Gifford Leland — Washington, D C
41 William E Lingelbach — Philadelphia, Pa
38 Stewart Mitchell — Cambridge
15 Samuel Eliot Morison — Boston
46 Otto Eduard Neugebauer — Providence, R I
34 Robert Henry Pfeiffer — Cambridge
34 David Moore Robinson — Baltimore, Md
23 Michael Ivanovich Rostovtzeff — New Haven, Conn
27 George Sarton — Cambridge
38 Bernadotte Everly Schmitt — Chicago, Ill
36 Donald Scott — Cambridge
26 Herbert Joseph Spinden — Brooklyn, N Y
32 Charles Holt Taylor — Cambridge
11 Alfred Marston Tozzer — Cambridge
39 Henry Rouse Viets — Brookline

CLASS IV, SECTION III—*Philology*—49

33 William Nickerson Bates — Philadelphia, Pa
35 Charles Henry Beeson — Chicago, Ill
33 Campbell Bonner — Ann Arbor, Mich
25 Robert Johnson Bonner — Chicago, Ill
41 Giuseppe Antonio Borgese — Chicago, Ill
21 Carl Darling Buck — Chicago, Ill
18 Edward Capps — Princeton, N J
20 Walter Eugene Clark — Cambridge
46 George Raleigh Coffman — Chapel Hill, N C
32 Ronald Salmon Crane — Chicago, Ill
32 Morris William Croll — Princeton, N J
44 Henry Grattan Doyle — Washington, D C
20 Franklin Edgerton — New Haven, Conn
40 Serge Elisséeff — Cambridge
14 Jeremiah Denis Mathias Ford — Cambridge
16 Louis Herbert Gray — New York, N Y
25 William Chase Greene — Cambridge
13 Charles Burton Gulick — Cambridge
34 Austin Morris Harmon — New Haven, Conn
31 Raymond Dexter Havens — Baltimore, Md
18 George Lincoln Hendrickson — New Haven, Conn
17 William Guild Howard — Cambridge
40 Werner Wilhelm Jaeger — Watertown
32 (Ralph) Hayward Keniston — Ann Arbor, Mich
34 Roland Grubb Kent — Wynnewood, Pa
33 Hans Kurath — Ann Arbor, Mich
39 Henry Carrington Lancaster — Baltimore, Md
33 Ivan Mortimer Linforth — Berkeley, Cal
44 Elias Avery Lowe — Princeton, N J
35 Benjamin Dean Meritt — Princeton, N J
28 William Albert Nitze — Los Angeles, Cal
32 George Rapall Noyes — Berkeley, Cal
33 Howard Rollin Patch — Northampton
32 Arthur Stanley Pease — Cambridge
11 Fred Norris Robinson — Cambridge
38 Hyder Edward Rollins — Cambridge
31 Robert Kilburn Root — Princeton, N J
35 Henry Arthur Sanders — Ann Arbor, Mich
18 Rudolph Schevill — Berkeley, Cal
43 Jean Joseph Seznec — Cambridge
45 George Wiley Sherburn — Cambridge
45 Taylor Starck — Cambridge
39 John Strong Perry Tatlock — Berkeley, Cal
32 William Thomson — South Lincoln
11 Charles Cutler Torrey — New Haven, Conn
47 William Freeman Twaddell — Providence, R I
30 Ernest Hatch Wilkins — Newton Center
33 Harry Austryn Wolfson — Cambridge
39 William Hoyt Worrell — Ann Arbor Mich

CLASS IV, SECTION IV—*The Fine Arts and Belles Lettres*—51

43 Leonard Bacon — Peace Dale, R I
26 Frank Weston Benson — Salem
32 (William) Welles Bosworth — Locust Valley, N Y
47 Richard Burgin — Brookline
42 John Nash Douglas Bush — Cambridge
33 John Alden Carpenter — Chicago, Ill
45 Samuel Chamberlain — Marblehead
32 Chalmers Dancy Clifton — New York, N Y
32 Kenneth John Conant — Cambridge
46 William George Constable — Cambridge
34 Samuel Foster Damon — Providence, R I.
47 John Roderigo Dos Passos — Provincetown
32 George Harold Edgell — Cambridge
21 William Emerson — Cambridge
30 John Erskine — New York, N Y.
18 Edward Waldo Forbes — Cambridge
31 Robert Frost — South Shaftsbury, Vt
27 Wallace Goodrich — Manchester
44 Walter Gropius — Lincoln
31 Robert Silliman Hillyer — Old Greenwich, Conn
27 Charles Hopkinson — Manchester
12 Mark Antony DeWolfe Howe — Boston
38 Joseph Hudnut — Cambridge
18 Archer Milton Huntington — New York, N Y
45 William Alexander Jackson — Cambridge
38 Howard Mumford Jones — Cambridge
42 Otto Kinkeldey — Ithaca, N Y
47 Milton Edward Lord — Boston
21 Charles Donagh Maginnis — Brookline

31 Paul Manship	New York, N Y
31 Daniel Gregory Mason	New York, N Y
31 Frank Jewett Mather	Washington Crossing, Pa
44 Charles Rufus Morey	Princeton, N J
47 Lewis Mumford	Amenia, N Y
31 Kenneth Ballard Murdock	Boston
(24) 32 Anthony John Philpott	Arlington
41 Walter Hamor Piston, Jr	Belmont
21 Chandler Rathfon Post	Cambridge
22 Paul Joseph Sachs	Cambridge
14 Ellery Sedgwick	Boston
19 Henry Dwight Sedgwick	Dedham
33 David Stanley Smith	Woodbridge, Conn
39 Francis Henry Taylor	New York, N Y
43 Randall Thompson	Princeton, N J
44 Karl Victor	Cambridge
45 Martin Wagner	Cambridge
46 Edward Augustus Weeks, Jr	Boston
39 Karl Ephraim Weston	Williamstown
44 Herbert Eustis Winlock	New York, N Y
22 Charles Henry Conrad Wright	Cambridge
46 William Wilson Wurster	Cambridge

FELLOWS EMERITI—33

CLASS I—Mathematical and Physical Sciences—5

Class I, Section I—2

15 Frank Lauren Hitchcock	Belmont
[12] 44 Frederick Shenstone Woods	Newton Center

Class I, Section III 1

14 Samuel Cate Prescott	Brookline

Class I, Section IV 2

23 William Hovgaard	Brooklyn, N Y
30 George Edmond Russell	Lexington

CLASS II—Natural and Physiological Sciences 7

Class II, Section I—4

09 Reginald Aldworth Daly	Cambridge
[03] 44 Charles Palache	Cambridge
17 Percy Edward Raymond	Lexington
11 Hervey Woodburn Shimer	Hingham

Class II, Section II -1

29 Joseph Horace Faull	Cambridge

Class II, Section III—1

15 Charles Thomas Brues	Newtonville

Class II, Section IV—1

15 Reid Hunt	Boston

CLASS III—The Social Arts—5

Class III, Section I—1

(28) 32 Edmund Allen Whitman	Cambridge

Class III, Section II—1

31 Sidney Bradshaw Fay	Cambridge

Class III, Section III,—2

32 William James Cunningham	Cambridge
36 Elton Mayo	Polesden Lacey, England

Class III, Section IV—1

36 Clair Elsmere Turner	Arlington

CLASS IV The Humanities—16

Class IV, Section I—2

28 Walter Fenno Dearborn	Cambridge
21 William Ernest Hocking	Madison, N H

Class IV, Section II—5

12 George Henry Chase	Cambridge
21 William Scott Ferguson	Cambridge
33 Henry Thatcher Fowler	Harmony, R I
22 George La Piana	Wellesley
20 Charles Howard McIlwain	Princeton, N J

Class IV, Section III—5

30 James Geddes, Jr	Brookline
38 Richmond Laurin Hawkins	Cambridge
32 Ernest Felix Langley	Cambridge
44 La Rue Van Hook	New York, N. Y.
33 George Benson Weston	Cambridge

Class IV, Section IV—4

29 Charles Townsend Copeland	Cambridge
41 Archibald Thompson Davison	Lincoln
29 Edward Burlingame Hill	Francestown, N H
[35] 44 Walter Raymond Spalding	Cambridge

FOREIGN HONORARY MEMBERS—119

(Number limited to one hundred and fifty)

CLASS I—MATHEMATICAL AND PHYSICAL SCIENCES—31

SECTION I—*Mathematics and Astronomy*—12

39	Arnaud Denjoy	Paris
34	Ronald Aylmer Fisher	Cambridge, England
20	Jacques Salomon Hadamard	Paris
27	Ejnar Hertzsprung	Leiden
45	Sir Harold Spencer Jones	Greenwich
46	Bertil Lindblad	Stockholm
47	Edward Arthur Milne	Oxford
46	Jan Hendrik Oort	Leiden
47	Meghnad N Saha	Calcutta
47	G A Shajn	Simeis, U S S R
15	Charles Jean de la Vallée Poussin	Louvain
29	Hermann Weyl	Princeton, N J

CLASS I, SECTION II—*Physics*—6

29	Vilhelm Frimann Koren Bjerknes	Oslo
45	Niels Bohr	Copenhagen
24	Albert Einstein	Princeton, N J
29	James Franck	Chicago, Ill
29	Abram F Joffé	Leningrad
47	Sir George Paget Thomson	London

CLASS I, SECTION III—*Chemistry*—7

29	Johannes N Bronsted	Copenhagen
27	Peter Debye	Ithaca, N Y
33	Jaroslav Heyrovsky	Prague
33	Fritz Paneth	Durham
38	Leopold Ruzicka	Zurich
38	Nevil Vincent Sidgwick	Oxford
29	Heinrich Wieland	Munich

CLASS I, SECTION IV—*Technology and Engineering*—6

36	Edward Victor Appleton	London
46	Clarence Decatur Howe	Ottawa
34	Luigi Lombardi	Rome
29	Ludwig Prandtl	Göttingen
29	Emil Probst	Oxford
31	Karl Willy Wagner	Friedrichsdorf

CLASS II—NATURAL AND PHYSIOLOGICAL SCIENCES—29

SECTION I—*Geology, Mineralogy, and Physics of the Globe*—6

36	Raoul Blanchard	Grenoble, France
29	Léon William Collet	Geneva
34	Arthur Holmes	Edinburgh
22	Emmanuel de Margerie	Paris
44	Ezequiel Ordoñez	Mexico, D F
17	Wong Wen-hao	Nanking

CLASS II, SECTION II—*Botany*—8

32	Frederick Orpen Bower	Ripon
46	Rudolf Florin	Stockholm
47	P Maheshwari	Dacca, India
32	Kingo Miyabe	Sapporo, Japan
42	Lorenzo Raimundo Parodi	Buenos Aires
47	Alf Erling Porsild	Ottawa
29	Otto Renner	Jena
35	Sir William Wright Smith	Edinburgh

CLASS II, SECTION III—*Zoology and Physiology*—9

38	Edgar Douglas Adrian	Cambridge, England
20	Maurice Caullery	Paris
38	Emmanuel Fauré-Frémiet	Paris
34	Archibald Vivian Hill	London
41	Bernado Alberto Houssay	Buenos Aires
47	Augustus Daniel Imms	Tipton St John, Devonshire
31	August Krogh	Copenhagen
30	Louis Édouard Lapicque	Paris
28	Sir D'Arcy Wentworth Thompson	St Andrews

CLASS II, SECTION IV—*Medicine and Surgery*—6

39	Sir Aldo Castellani	Rome
27	Sir Henry Hallett Dale	London
33	Sir Arthur Keith	London
28	Mikinosuke Miyajima	Tokyo
18	Sir Charles Scott Sherrington	Cambridge, England
36	(Jean) Hyacinthe Vincent	Paris

CLASS III—THE SOCIAL ARTS—30

SECTION I—*Jurisprudence*—12

44	Victor Andres Belaunde	Lima
47	Paal Berg	Oslo
38	Mircea Djuvara	Bucharest
33	François Geny	Nancy
38	Arthur Lehman Goodhart	Oxford
39	Wilfrid Arthur Greene, Baron Greene	Holmbury St Mary, Surrey
33	Hans Kelsen	Berkeley, Cal
38	Rt Hon Lord Macmillan	Ewhurst, Surrey
33	Juljusz Makarewicz	Lwów

33 Giorgio Del Vecchio	Rome
38 Rt Hon Lord Wright	Burbage, Wilts
38 John C H Wu	Vatican City

SECTION II—*Government, International Law, and Diplomacy*—5

38 Dionisio Anzilotti	Rome
46 Winston Churchill	London
32 Paul Claudel	Paris
32 Hu Shih	Peiping
38 Kenzo Takayanagi	Tokyo

SECTION III—*Economics and Sociology*—9

32 Arthur Lyon Bowley	Haslemere, Surrey
39 Henry Clay	Oxford
44 Daniel Cosío Villegas	Mexico, D F
35 Luigi Einaudi	Turin
32 Ralph George Hawtrey	London
35 René Maunier	Paris
28 Arthur Cecil Pigou	Cambridge, England
32 Charles Rist	Versailles
45 Dennis Holme Robertson	Cambridge, England

SECTION IV—*Administration and Affairs*—4

33 Gösta A Bagge	Stockholm
38 Heinrich Brüning	Cambridge, Mass
45 Alfredo Lorenzo Palacios	Buenos Aires
38 B Seebohm Rowntree	North Dean, Bucks

CLASS IV—THE HUMANITIES—29

SECTION I—*Theology, Philosophy, and Psychology*—6

28 Benedetto Croce	Naples
29 Étienne Gilson	Melun
28 Wolfgang Köhler	Swarthmore, Pa
37 Henri Piéron	Paris
46 Francisco Romero	Buenos Aires
47 Godfrey Hilton Thomson	Edinburgh

SECTION II—*History, Archaeology, and Anthropology*—5

33 Rafael Altamira y Crevea	Madrid
36 Marcel Aubert	Paris
33 Friedrich Meinecke	Berlin-Dahlem
40 Martin Persson Nilsson	Lund
31 George Macaulay Trevelyan	Cambridge, England

SECTION III—*Philology*—9

44 Amado Alonso	Arlington, Mass
47 Hamilton Alexander Rosskeen Gibb	Oxford
47 Joseph Klausner	Jerusalem
36 Paul Kretschmer	Vienna
32 Paul Mazon	Paris
17 Ramón Menéndez Pidal	Madrid
45 Tomás Navarro Tomás	New York, N Y
[12] 28 Hanns Oertel	Munich
32 Frederick William Thomas	Bodicote nr Banbury

SECTION IV—*The Fine Arts and Belles Lettres*—9

40 Fernand Baldensperger	Paris
30 Alfredo Casella	Rome
40 Paul Hindemith	New Haven, Conn
34 Serge Koussevitzky	Boston
27 Gilbert Murray	Oxford
31 Edgar Allison Peers	Liverpool
27 Henri Rabaud	Paris
41 Jean Julius Christian Sibelius	Helsink
40 Igor Stravinsky	Hollywood, Cal

ALPHABETICAL INDEX TO LISTS OF MEMBERS

The letters F, FE and FHM refer to the lists of Fellows, Fellows Emeriti and Foreign Honorary Members, respectively. The class and section are indicated by the numerals following

STATUTES

THE AMERICAN ACADEMY OF ARTS AND SCIENCES

Adopted November 8, 1911 *amended* May 8, 1912, *January* 8, *and May* 14, 1913, *April* 14, 1915, *April* 12, 1916, *April* 10, 1918, *May* 14, 1919, *February* 8, *April* 12, *and December* 13, 1922, *February* 14, *March* 14, *and October* 10, 1923, *March* 10, 1926, *May* 9, 1928, *April* 8, *and November* 11, 1931, *April* 12, 1933, *February* 14, 1934, *December* 14, 1938, *January* 11, *April* 12, 1939, *May* 8, 1940, *May* 14, 1941, *November* 18, 1942, *and January* 12, 1944, *May* 9, 1945, *November* 14, 1945, *February* 2, 1946, *October* 9, 1946, *and October* 8, 1947

Chapter I

THE ACADEMY AND ITS CORPORATE SEAL

ARTICLE 1. The American Academy of Arts and Sciences is a body politic and corporate by the same name, forever, established by the Council and House of Representatives in General Court of the Province of Massachusetts Bay as recorded in Chap 46 of the Acts of 1779

ARTICLE 2. As enacted above, the stated end and design of the institution of the said academy is to promote and encourage the knowledge of the antiquities of America, and of the natural history of the country, and to determine the uses to which the various natural productions of the country may be applied, to promote and encourage medical discoveries, mathematical disquisitions, philosophical enquiries and experiments, astronomical, meteorological and geographical observations, and improvements in agriculture, arts, manufacture and commerce; and, in fine, to cultivate every art and science which may tend to advance the interest, honor, dignity and happiness of a free, independent and virtuous people.

ARTICLE 3. The Corporate Seal of the Academy shall be as here depicted.

ARTICLE 4. The Secretary shall have the custody of the Corporate Seal

See Chap v, art 3 chap vi, art 1

CHAPTER II

MEMBERSHIP AND DUES

ARTICLE 1. The Academy shall consist of Fellows, elected from the citizens or residents of the United States of America, Fellows Emeriti, and Foreign Honorary Members. They are arranged in four Classes, according to the Arts and Sciences in which they are severally proficient, and each Class shall be divided into four Sections, namely:

CLASS I. *The Mathematical and Physical Sciences*

- Section 1. Mathematics and Astronomy
- Section 2. Physics
- Section 3. Chemistry
- Section 4. Technology and Engineering

CLASS II. *The Natural and Physiological Sciences*

- Section 1. Geology, Mineralogy, and Physics of the Globe
- Section 2. Botany

Section 3 Zoology and Physiology

Section 4 Medicine and Surgery

Class III. *The Social Arts*

Section 1. Jurisprudence

Section 2. Government, International Law, and Diplomacy

Section 3. Economics and Sociology

Section 4 Administration and Affairs

Class IV *The Humanities*

Section 1. Theology, Philosophy, and Psychology

Section 2. History, Archaeology, and Anthropology

Section 3. Philology

Section 4. The Fine Arts and Belles Lettres

Article 2 The number of Fellows shall not exceed One thousand, of whom not more than Eight hundred shall be residents of Massachusetts, nor shall there be more than Two hundred and seventy-five in any one Class

Any Fellow of the Academy on retiring from his academic or other regular duties may, if he so requests in writing, and with the approval of the Council, be transferred to the status of Fellow Emeritus.

Fellows Emeriti shall be exempt from payment of dues. They may not hold elective office in the Academy, nor serve on Standing Committees, nor vote at meetings, but shall have all the other privileges of Fellowship.

Fellows Emeriti shall be separately classified and shall be outside the statutory limit set on the total number of Fellows and the number in a given Class.

See Chap ix, art 3, chap x, art 1

Article 3 The number of Foreign Honorary Members shall not exceed One hundred and fifty. They shall be chosen from citizens of foreign countries most eminent for their discoveries and attainments in any of the Classes above enumerated. There shall be not more than Forty-five in any one Class

Article 4 Diplomas signed by the President and the Vice-President of the Class to which the member belongs, and countersigned by the Secretary, shall be given to Fellows and Foreign Honorary Members.

Article 5. If any person, after being notified of his election as Fellow or Foreign Honorary Member, shall neglect for six months to accept in writing, his election shall be void.

Article 6 Every Fellow resident within fifty miles of Boston hereafter elected shall pay an Admission Fee of Ten Dollars: if he shall neglect to pay this Fee within six months of the date of his election, his election shall become void

Every Fellow resident within fifty miles of Boston shall pay such Annual Dues, not exceeding Fifteen dollars, as shall be voted by the Academy at each Annual Meeting, at which time they shall become due.

Every Fellow residing more than fifty miles from Boston elected after 1938 shall pay, and other non-resident Fellows may pay, Annual Dues equal to one-half the amount set for resident Fellows at each Annual Meeting and due on the same date.

Any Fellow shall be exempt from further payment of Annual Dues who has paid such dues for forty years, or having attained the age of seventy-five, has paid dues for twenty-five years

Any Fellow may also be exempt from further payment of annual dues upon payment into the treasury of the Academy the sum of Two hundred dollars in addition to his previous payments

Any Fellow not previously subject to Annual Dues who takes up his residence within fifty miles of Boston, shall pay to the Treasurer, within three months thereafter, Annual Dues for the current year, and if he shall neglect to make this payment within the specified time, after having been notified by the Treasurer of the requirements of this Article of the Statutes, he shall cease to be a Fellow

Article 7 Any Fellow, resident or non-resident, who shall neglect to pay his Annual Dues for six months after they are due and who ignores notification by the Treasurer of

the requirements of this Article of the Statutes shall cease to be a Fellow.

ARTICLE 8. Only Fellows who pay Annual Dues or have commuted them may hold elective office in the Academy or serve on Standing Committees or vote at meetings

ARTICLE 9 Upon petition of any Fellow, the Council may by a majority vote suspend the application of any penalties hereinabove prescribed in this chapter for an additional period of time not longer than three months.

ARTICLE 10 If, in the opinion of a majority of the entire Council, any Fellow or Foreign Honorary Member shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his membership, and if three-fourths of the Fellows present out of a total attendance of not less than fifty at a Stated Meeting, or at a Special Meeting called for the purpose, shall adopt this recommendation, his name shall be stricken from the Roll

See Chap III, chap VI, art 5 and 6, chap X, art 1

CHAPTER III

NOMINATION AND ELECTION OF FELLOWS AND FOREIGN HONORARY MEMBERS

The procedure for nomination and election of Fellows and Foreign Honorary Members shall be as follows:

ARTICLE 1. Nominations may be made at any time by any two Fellows in writing on forms to be provided by the Secretary and shall be referred by him to the Committee on Membership.

The Committee on Membership shall meet following the stated meetings of the Academy in May, November, February and March, and at such other times as it may determine, to appraise nominations received by it from the Fellows from time to time, to originate further nominations, and to approve as candidates for election those receiving the favorable vote of two-thirds of the Committee members present in any meeting attended by not less than five of its members.

Immediately following its meeting in February, the Committee shall cause to be sent to every Fellow a list of nominees, with biographical and professional data thereon, together with names of nominators, for appraisal, expression of preference, or other comment by the Fellows.

The Committee, at its March meeting, shall review all nominations, together with comments by the Fellows thereon, and shall compile a list of approved candidates for the annual election of Fellows and Foreign Honorary Members. It shall present this list together with data pertaining thereto to the Council not later than at the stated meeting of the Council in April.

The Council, by vote of the majority of members present at a meeting, shall make final nominations from the list of approved persons recommended by the Committee on Membership for election by the Fellows

ARTICLE 2 Election of Fellows and Foreign Honorary Members shall be made by a majority of the Fellows present at the Annual Meeting in May, from the nominations presented at that meeting by the Council.

ARTICLE 3 Each Fellow or Foreign Honorary Member shall be notified in writing by the Secretary immediately following his election.

See Chap II, chap VI, art 5, chap X, art 1, chap XI, art 1 (II)

CHAPTER IV

OFFICERS

ARTICLE 1 The Officers of the Academy shall be a President (who shall be Chairman of the Council), four Vice-Presidents (one from each Class), a Secretary (who shall be Secretary of the Council), a Treasurer, a Librarian, and an Editor, all of whom shall be elected by ballot at the Annual Meeting, and shall take office at the close of that meeting, and shall hold their respective offices for one year, and until others are duly chosen and take office.

There shall be also sixteen Councillors, one from each Section of each Class At each Annual Meeting four Councillors, one from each Class, shall be elected by ballot to serve for a term of four years, and they shall take office at the close of that meeting, and shall hold office

until others are duly chosen and take office. The same Fellows shall not be eligible for two successive terms.

The Councillors, with the officers previously named, and the Chairmen of the Standing Committees, *ex officiis*, shall constitute the Council.

See Chap xi, art 1

ARTICLE 2. If any officer be unable, through death, absence, or disability, to fulfill the duties of his office, or if he shall resign, his place may be filled by the Council in its discretion for any part or the whole of the unexpired term.

ARTICLE 3. At the Stated Meeting in March, the President shall appoint a Nominating Committee of four Fellows having the right to vote, one from each Class This Committee shall prepare a list of nominees for the several offices to be filled, and for the Standing Committees, and file it with the Secretary not later than four weeks before the Annual Meeting

ARTICLE 4 Independent nominations for any office, if signed by at least twenty Fellows having the right to vote, and received by the Secretary not less than ten days before the Annual Meeting, shall be included in the election procedure

ARTICLE 5 The Secretary shall prepare for use in voting at the Annual Meeting a ballot containing the names of all persons duly nominated for office

CHAPTER V

THE PRESIDENT

ARTICLE 1 The President, or in his absence a Vice-President, shall preside at meetings of the Academy

See Chap. vi, art 3

ARTICLE 2. The President shall be the chief executive officer of the Academy He shall present to the Council for its consideration all matters pertinent to the interests of the Academy and to the discharge of its obligations to the community or to the advancement of scholarship.

ARTICLE 3. Any deed or writing to which the Corporate Seal is to be affixed, except leases of real estate, shall be executed in the name of the Academy by the President or in the event of his death, absence, or inability, by one of the Vice-Presidents, when thereto duly authorized by the Council.

ARTICLE 4. In case of incapacity of the President, the Council shall designate a Vice-President to carry out the duties of the office

See Chap ii, art 4, chap iv, art 1, 3, chap vi, art. 3, chap viii, art 4, chap x, art 3, chap. xi, art 1 (ii), (iii), (x), chap. xii, art 1

CHAPTER VI

THE SECRETARY

ARTICLE 1 The Secretary shall provide for the custody of the Charter, Corporate Seal, Statute Book, Journals of the Academy, and other Archives

ARTICLE 2 He shall be responsible for the correspondence of the Academy and of the Council. At each meeting of the Council he shall present any important communications addressed to the Academy which have been received since the previous meeting, and at the next meeting of the Academy he shall present such matters as the Council may determine

ARTICLE 3 He shall attend the meetings of the Academy and the Council and shall arrange for the keeping of a faithful record of the attendance and of the proceedings. In the absence of the President and of all the Vice-Presidents, he shall call the meeting to order and preside until a chairman is chosen by majority vote of the Fellows present

ARTICLE 4 He shall apprise officers and committees of their election or appointment, and inform the Treasurer and the Chairman of each Standing Committee of appropriations of money voted by the Academy.

ARTICLE 5. He shall notify all persons who may be elected Fellows or Foreign Honorary Members, send to each a copy of the Statutes, and on their acceptance issue the proper Diploma After all elections, he shall insert in the Records the names of the Fellows by whom the successful nominees were proposed.

ARTICLE 6. He shall keep and cause to be printed annually a list of the Fellows and Foreign Honorary Members, arranged in their several Classes and Sections, and a list of Fellows and Foreign Honorary Members of whose deaths he has been informed.

ARTICLE 7. He shall arrange for the preservation of records of the death of Fellows and Foreign Honorary members and biographical notices published on the occasion of their death, or at other times.

See Chap i, art. 2; chap ii, art 4, chap iii, chap iv, art 1, 3, 4, 5, chap ix, art 3, chap xi, art 1 (iii), 2, chap xii, art 1, 3.

CHAPTER VII

THE TREASURER AND THE TREASURY

ARTICLE 1. The Treasurer shall collect all money due or payable to the Academy and all gifts or bequests made to it. He shall pay all bills due and payable by the Academy when approved by the proper officers He shall sign all leases of real estate in the name of the Academy. He shall be the official custodian of all bonds, stocks and other securities and, with the written approval of any one member of the Committee on Finance, he shall have full authority to sell and transfer, invest and reinvest from time to time in such manner and upon such terms as shall to him seem best, the whole or any part of the personal property of the said Academy.

He shall keep a faithful account of all receipts and expenditures, submit his accounts annually to the Auditing Committee, and render them at the expiration of his term of office, or whenever required to do so by the Academy or the Council

He shall keep separate accounts of the income of the Rumford Fund, and of all other special Funds, and of the Appropriation thereof, and render them annually.

He shall fund all payments received in commutation of Dues, their income only, to be applied toward current expenditures.

His accounts shall always be open to the inspection of the Council.

ARTICLE 2. He shall report annually to the Council at its March meeting on the expected income of the various Funds and from all other sources, together with appropriations needed by Officers and Standing Committees for the ensuing fiscal year. He shall also report the names of all Fellows who may be then delinquent in the payment of their Annual Dues

ARTICLE 3 He shall give such security for the trust reposed in him as the Academy may require.

ARTICLE 4 With the approval of a majority of the Committee on Finance, he may appoint an Assistant Treasurer to perform his duties, for whose acts, as such assistant, he shall be responsible, or, with like approval and responsibility, he may employ any Trust Company doing business in Boston as his agent for the same purpose, the compensation of such Assistant Treasurer or agent to be fixed by the Committee on Finance and paid from the Funds of the Academy.

ARTICLE 5 At the Annual Meeting he shall report in print all his official doings for the preceding year, stating the amount and condition of all the property of the Academy entrusted to him, and the character of the investments

ARTICLE 6 The Financial Year of the Academy shall begin with the first day of April

ARTICLE 7 No person or committee shall incur any debt or liability in the name of the Academy, unless in accordance with a previous vote and appropriation therefor by the Academy or the Council, or sell or otherwise dispose of any property of the Academy, except cash or invested funds, without previous consent and approval of the Council

See Chap ii, art 2, 6, 7, 8, chap. iv, art 1, chap vi, art 4, chap ix, art 6, chap xi, art 1 (i), (iv), (v), art 2, chap xii, art 1

CHAPTER VIII

THE LIBRARIAN AND THE LIBRARY

ARTICLE 1. The Librarian shall have charge of the Library and keep a correct catalog of it

ARTICLE 2. The Librarian shall have authority to expend such sums as may be appropriated by the Academy for the purchase, repair, or maintenance of books,

periodicals, etc., and for defraying other necessary expenses connected with the Library.

ARTICLE 3 All books procured from the income of the Rumford Fund or other special funds shall contain a bookplate expressing the fact.

ARTICLE 4. The Librarian shall have the custody of the publications of the Academy With the advice and consent of the President, he may effect exchanges with other associations

See Chap. iv, art 1, chap xi

CHAPTER IX

THE EDITOR AND THE PUBLICATIONS

ARTICLE 1 The Editor shall have charge of the conduct through the press of the publications of the Academy Together with the Committee on Publications he shall determine the contents of the publications

ARTICLE 2. The publications of the Academy shall be as follows.

(i) The Proceedings shall be published at least semi-annually as soon as may be possible after the Annual May Meeting, and the stated December meeting next following, and shall contain a record of each stated or special meeting of the Academy They shall be known respectively as the Summer and Winter number of the Proceedings

The Summer number of the Proceedings shall include reports of the officers and standing committees for the preceding year, a list of the officers, councillors and members of standing committees elected at the preceding Annual Meeting, and such other matter as the Publication Committee may approve

The Winter number of the Proceedings shall include a current list of officers, councillors, standing committees, Fellows and Foreign Honorary Members, the Statutes of the Academy, the Act of Incorporation of 1780 and its amendments, and such biographical notices or other matter as the Committee on Publications may approve

In the discretion of the Committee on Publication, interim numbers of the Proceedings may be issued for the publication of accepted serial papers or other scholarly material.

(ii) Memoirs, monographs and volumes of collected papers may be published from time to time.

(iii) The Bulletin of the American Academy of Arts and Sciences shall be published eight times each year preceding the stated meetings, containing notices of such meetings, communications from the council or officers, and such other matter as may be of timely interest to the Fellows

ARTICLE 3 A copy of the Summer and Winter numbers of the Proceedings shall be mailed to each Fellow, Fellow Emeritus, and Foreign Honorary Member

A copy of the Bulletin shall be mailed to each Fellow and Fellow Emeritus.

A copy of any Interim number of the Proceedings shall be mailed only to those Fellows, Fellows Emeriti, and Foreign Honorary Members, who shall make written request to the Secretary for that number.

ARTICLE 4 Fellows who pay or have commuted the Annual Dues, Fellows Emeriti, and Foreign Honorary Members shall be entitled, upon written request to the Librarian, to receive gratis one copy of each number of Proceedings, memoirs, monographs or series of collected papers, published by the Academy, which have been issued after their election, and are available.

ARTICLE 5 Not more than Two hundred extra copies of each paper printed in the Proceedings shall be placed at the disposal of the author without charge

ARTICLE 6 The Editor shall have the authority to expend for printing and other expenses of publication such sums as may be appropriated by the Academy for such purposes, also such sums as may be made available to him by the Council from any source for particular publications under the sponsorship of the Academy

See Chap iv, art 1, chap xi, art 1 (vi)

CHAPTER X

THE COUNCIL

ARTICLE 1. The Council shall exercise general supervision over all affairs of the Academy

not explicitly reserved to the Academy as a whole.

It shall consider all nominations of Fellows and Foreign Honorary members duly sent to it by the Committee on Membership, and act upon them in accordance with the provisions of Chapter III.

With the consent of the person concerned it shall have power to present to the Academy a proposal to transfer in respect to status, Class, or Section.

ARTICLE 2. Nine members shall constitute a quorum.*

ARTICLE 3 It shall act upon all resignations and forfeitures of membership in the Academy.

It shall appoint all agents and subordinates not otherwise provided for by the Statutes, prescribe their duties, and fix their compensation They shall hold their respective positions during the pleasure of the Council

It shall fill any vacancy caused by death, resignation or incapacity of any officer

ARTICLE 4. It may appoint for terms not exceeding one year, and prescribe the functions of such committees of its number or of the Fellows of the Academy, as it may deem expedient, to facilitate the administration of the affairs of the Academy or to promote its interests

ARTICLE 5. At the stated March meeting of the Academy it shall recommend for action the appropriations which in the opinion of the Council should be made for the ensuing fiscal year and the Annual Dues therefor.

It may recommend special appropriations at any Stated Meeting of the Academy, or at a Special Meeting, in the call for which such business shall have been included.

See Chap ii, art 2, 10, chap iii, art 1, 2, chap iv, art 1, 2, chap. v, art. 2, 3, chap vi, art 2, 3, chap vii, art. 1, 2, 7, chap ix, art 6, chap xi, art 1, chap xii, art 1, 4, 6

CHAPTER XI

STANDING COMMITTEES

ARTICLE 1. At the Annual Meeting of the Corporation the following Standing Committees shall be elected by ballot of the Fellows to serve from the time of their election until their successors shall have been elected.

(i) *The House Committee* shall consist of three Fellows who shall have general charge of maintaining the House of the Academy in suitable condition for the uses thereof approved by the Council.

The Chairman of the House Committee or his designate shall approve in writing all expenditures for repairs, services, supplies or operation of the House, including salaries of House Employees.

The House Committee, in consultation with the Treasurer, shall determine the equitable proportion of expense to be assessed for the use of the facilities of the House, which are approved by the Council for other than Academy activities.

(ii) *The Committee on Membership* shall consist of the President, ex-officio, as Chairman, and eight Fellows, not members of the Council, one from each Class to be elected annually to serve for two years, except that in the initial election one additional Fellow shall be elected from each Class to serve for one year only. It shall have the duties designated to it in Chapter III.

(iii) *The Committee on Meetings* shall consist of the President as Chairman, and the Secretary, ex-officio, and four other Fellows. It shall arrange for meetings of the Academy

(iv) *The Committee on Finance* shall consist of the Treasurer, ex-officio, as Chairman, and four other Fellows. It shall have general oversight of the investments of the Academy.

(v) *The Auditing Committee* shall consist of two Fellows who shall audit the accounts of the Treasurer with power to employ an expert and to approve his bill.

(vi) *The Committee on Publication* shall consist of the Editor as Chairman, ex-officio, and four other Fellows, one from each Class. It shall have the authority and the responsibility of determining the contents and of effecting the printing of the Publications of the Academy as set forth in Chapter IX.

(vii) *The Permanent Science Fund Committee* shall consist of seven Fellows. It shall

review all applications for grants addressed to it and shall from time to time recommend to the Council appropriate disbursements from the income received by the Academy from the Trustee of the Permanent Science Fund, for carrying out the purposes set forth in the Agreement and Declaration of Trust which governs the use of this Fund

(viii) *The Rumford Committee* shall consist of seven Fellows It shall invite applications for pecuniary assistance in support of researches in the fields of heat and light, including X rays, and it alone shall authorize the purchase of books, publications and apparatus at the charge of the income from the Rumford Fund It shall biennially recommend to the Council a candidate for the reception of the Premium to be awarded in accordance with the Rumford trust, and shall generally see to the proper execution of this trust.

(ix) *The C M Warren Committee* shall consist of seven Fellows It shall invite applications for pecuniary assistance from any person wishing to engage in research in any branch of chemistry and shall recommend to the Council such applications as seem to be worthy of aid, and such other disbursements from income of the C M Warren Fund as it deems appropriate to the advancement of research in chemistry.

(x) *The Amory Prize Committee* shall consist of seven Fellows It shall consider persons eligible and recommend to the Council the award by the President and Fellows of the Amory Prize and a gold medal or other token of honor and merit for each septennium beginning with that which was concluded on November 10, 1933, and thereafter, said award being in recognition of an invention or other contribution in the medical field specified in and according to the terms of the bequest of Francis Amory

ARTICLE 2 Each Standing Committee shall confine its recommendations and its expenditures to such sum in each fiscal year as shall have been notified to its Chairman by the Secretary of the Academy as appropriations voted by the Academy, or by the Treasurer as income available for its purposes.

ARTICLE 3. Each Standing Committee shall report to the Academy at the Annual Meeting, its acts of the previous year.

See Chap. iii, chap iv, art. 1, 3, chap vi, art. 4; chap vii, art 1, 2, 4, chap ix, art 1, 2.

CHAPTER XII

MEETINGS, COMMUNICATIONS, AND AMENDMENTS

ARTICLE 1. There shall be annually eight Stated Meetings of the Academy, namely, on the second Wednesday of October, November, December, January, February, March, April, and May Only at these meetings, or at adjournments thereof regularly notified, or at Special Meetings called for the purpose, shall appropriations of money be made or amendments of the Statutes be effected.

The Stated Meeting in May shall be the Annual Meeting of the Corporation

Special Meetings shall be called by the Secretary at the request of the President, of the Council, or of ten Fellows having the right to vote, and notifications thereof shall state the purpose for which the meeting is called

The Council shall have authority, as occasion may demand, to arrange additional meetings and to cancel any of the Statutory meetings, except that meetings for transacting business shall be held as required by the Statutes

ARTICLE 2 Except as otherwise provided, twenty-five Fellows having the right to vote shall constitute a quorum for the transaction of business at Stated or Special Meetings. Eighteen Fellows shall be sufficient to constitute a meeting for literary or scientific communications and discussions.

ARTICLE 3 Upon the request of the presiding officer or the Secretary, any motion or resolution offered at any meeting shall be submitted in writing.

ARTICLE 4 Fellows may introduce guests at any of the literary or scientific meetings of the Academy

ARTICLE 5. All amendments to the Statutes, whether proposed by Fellows or by the Council, shall be considered by the Council and reported with recommendations for action to the Academy. At a subsequent Stated Meeting, or at a Special Meeting called for the purpose, the notice for which in either case shall state this proposed amendment, the Academy shall act upon the amendment. Two-thirds of the Fellows present, in a meeting of not less than forty Fellows, must vote in the affirmative to enact the amendment

See Chap II, art 6, 10, chap III, art 1, 2, chap IV, art 1, 3, 4, 5, chap V, art 1, chap VI, art 2, 3, chap VII, art 2, 5, chap IX, art 2, chap X, art 5, chap XI, art 1, 3

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THE LINEAR COMPRESSION OF VARIOUS SINGLE CRYSTALS TO 30,000 kg/cm²

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BY P. W. BRIDGMAN

INVESTIGATIONS OF LIGHT AND HEAT MADE AND PUBLISHED WITH AID OF THE RUMFORD FUND

THE LINEAR COMPRESSION OF VARIOUS SINGLE CRYSTALS TO 30,000 kg/cm²

By P W Bridgman

Received Oct , 1947

Contents

Introduction

During the war a number of laboratories were actively engaged in searching for crystals capable of replacing quartz or rochelle salts for various purposes of transmission or reception, and in this search large programs of crystal growing were carried out Some of the crystals made in this way were large enough to permit measurements of linear compression, and I was fortunate enough to obtain a number for this purpose The results on these and one other, magnesium, form the subject of this paper The crystals investigated here were all such that their distortion under hydrostatic pressure is completely determined if the change of linear dimensions is known in three or fewer orthogonal directions That is, no monoclinic or triclinic crystals were investigated, although a number of these had been grown for piezo-electrical purposes and were available Neither were any cubic crystals investigated, such not having piezo-electric properties.

Before undertaking the measurements a preliminary investigation of the substance was made in the apparatus[1] for rapid determination of cubic compressibility to 40,000 to find whether there were any polymorphic transitions in the contemplated range, since measurements of linear compressibility in general have no significance when carried through a transition point Among the available substances several were found with polymorphic transitions below 30,000 In general no attempt was made to measure the linear compressions of these The data for their volume compressions will be found in the previous paper describing the measurements with the 40,000 apparatus One of the substances with a transition, $MgSO_4 7H_2O$, was however measured in the low pressure range below its first transition

Apparatus and Method

The method used in this work was that of the "lever • piezometer," in which the change of dimensions of the specimen is magnified with a lever which moves a wire carrying a current over a contact fixed to the apparatus, the amount of motion being determined by potentiometer measurements of the resistance between a contact fixed to the wire and the contact over which it slides This method has been extensively employed hitherto[2] up to 12,000 kg/cm², and is the most accurate and sensitive method for the determination of the compression of solids used to date Its use to 30,000 in the present work is new The particular point in making the measurements over the wider range is the greater accuracy with which it is possible to determine the changes of compressibility with pressure, knowledge of which is important for the theory of the solid state Eventually it is intended to measure a large number of substances with similar apparatus over this range, such measurements will form a useful supplement to other less accurate measurements over wider ranges The particular crystals of this paper are well adapted for the first measurements in this range because their compressibilities are so high that certain irregularities which still persist in the apparatus

are without appreciable effect. Measurements by this method and in this range cannot yet be advantageously made on substances as incompressible as iron, but this part of the program must wait for further improvements, which are already well under way

Because of the emphasis on precision and the higher order terms it is necessary to take greater care with the measurement of pressure than is adequate, for instance, in the measurements to 100,000 It is now necessary to know the deviation of the manganin gauge from linearity. It has already been established[3] that this deviation is so slight that a calibration at two pressure fixed points is sufficient The gauges were calibrated by the transition of bismuth and the freezing of mercury at room temperature, the data for which are known The calibration must be made anew for every individual manganin coil, of which two were used in this work

The lever piezometer had to be specially designed and constructed It is somewhat smaller than formerly, being required to fit a hole 0 50 instead of 0 62 inches in diameter Furthermore, a different method of assembly had to be designed so that the insulating plug at the bottom of the cylinder need not be removed for every new setup, the assembly of this plug being much more time consuming in the 30,000 apparatus than with the former 12,000 apparatus Mr L H Abbot successfully designed an arrangement of spring clips which permitted the piezometer with specimen in place to be inserted as a single unit into the pressure cylinder from the moving plug end, this plug being naturally removed after every release of pressure Various calibrations have to be made on the piezometer for the magnification of the lever, the resistance of the wire and its pressure coefficient etc These calibrations were not essentially different from those previously necessary to 12,000 and need not be described further in detail

Various minor improvements in the technique of handling the 30,000 apparatus have been effected Some of these, having to do with methods of assembling the insulating plug and the packing ring for it, have already been described in the previous paper[4] giving new results to 100,000 I now have in all three complete equipments for reaching 30,000 These are somewhat individual in the difficulties which they present. The one in which the present measurements were made has perhaps given the most trouble. An especial trouble with this, not shown by the others, although the construction is identical as far as is evident, has been that the moving piston has a strong tendency to seize on the walls of the cylinder, resulting in abnormally high friction and also leak. This difficulty has been overcome by giving a proper hardness to the moving packing rings and by lightly copper plating before every run the steel parts which move over each other. In addition to these difficulties the most disastrous explosion yet experienced with any 30,000 apparatus occurred during this work. In the design used in the early measurements the insulating plug, where it projects from the pressure cylinder, was without external support for a distance of perhaps 5/16 inch on a diameter of 9/16 inch. There was some plastic swelling of this unsupported part, and in the course of the work this part had been refigured several times by removing altogether a few thousandths of an inch from the diameter The failure consisted in a complete collapse at the maximum pressure of the unsupported protruding part This failed by shear on an angle much blunter than 45°, releasing the contents of the cylinder, which were completely destroyed. Evidently the plastic flow in the protruding part, which was of Rockwell C hardness 59, had proceeded beyond the limit of tolerance. The new design was made with only half as long a protruding part, and to date no further difficulty has occurred

The methods of calculation in the following were like those previously used in the lower range, and need not be further described The results are essentially differential results with respect to American Ingot iron, the absolute compressibility of which has already been established[5] over this range by a different method. By making calibrating runs with iron, taking the difference between the calibrating run and the actual run and using in the calculation the known absolute value for iron, the absolute changes of dimension in the various crystallographically independent directions could be eventually obtained and tabulated. From the linear changes of dimensions the change of volume was then calculated In this calculation five place logarithms had to be used, four places being sufficient for the linear changes. Finally, the relative lengths and volumes were calculated from the changes, and recorded in the tables given here.

In the following a rough measure is given of the order of accuracy by recording the average deviation of a single experimental point from a

smooth curve in terms of the percentage of the differential change of dimensions at the highest pressure. The calculations involved first determining at every pressure what the displacement would have been if the relation with pressure had been linear passing through the top point, then plotting the deviation from linearity as a function of pressure, and finally passing a smooth curve through the deviation points. The sum of the deviations from this smooth curve of all the points was obtained by addition with the dividers, and this sum was divided by the total number of observations and the displacement at the maximum to get the average percentage deviation above In the usual routine, 17 readings uniformly scattered over the entire range were made in addition to an initial seasoning application of 10,000. The 17 readings were made with increasing and decreasing pressure, the decreasing readings being staggered between the increasing readings. The "probable" error of the result tabulated is of course much less than the irregularity of a single reading, perhaps something of the order of one quarter of it for a total of 17 readings, neglecting any systematic error. Furthermore, this error is on the differential compressibility, the absolute compressibility is more accurate by an amount depending on the difference between the substance in question and iron

Detailed Data

The detailed presentation of data now follows The substances are given first for which measurements in two directions were sufficient and then those which demanded three. In each section the order is, with two exceptions, the order of increasing volume compression at 30,000. The results are given in tables, length and volume at 2,500, 5,000, and then at 5,000 intervals to 30,000. No attempt has been made to find a universal formula which would cover all the data. A second degree expression such as was usually adequate in the former range up to 12,000 is definitely not adequate in most of the cases, although frequently the failure is by a small amount Most of the substances in the following are conventional enough in their behavior Only two have markedly unusual features $NiSO_4 6H_2O$, which has a very marked transition of the second kind in one direction, and benzil, which has a more complicated anomaly

Magnesium. This metal is included here with other dissimilar substances because its absolute compressibility is high enough to permit acceptable measurements with the present apparatus. The material was from the same crystal as that previously measured[6] to 12,000. The results are given in Table I. For the parallel direction the

TABLE I

MAGNESIUM

Pressure kg/cm²	Length ⊥ hex axis	Length ‖ hex axis	Volume
0	1 00000	1 00000	1 00000
2,500	99775	99770	99320
5,000	99553	99542	98657
10,000	99122	99100	97366
15,000	98716	98683	96166
20,000	98322	98280	95010
25,000	97954	97904	93938
30,000	97612	97548	92944

mean deviation of a single reading from a smooth curve was 0 17 per cent, and for the perpendicular direction 0 22 per cent. Compared with previous results the changes of length at 10,000 found now are about 3 per cent less than those formerly found The curvature or deviation from linearity in the parallel direction is not greatly different from that found before The curvature in the perpendicular direction, on the other hand, is now materially less than before The curvature previously found in the perpendicular direction was 50 per cent greater than that in the parallel direction, whereas now the two curvatures are equal within 1 per cent. The compressions in the two directions now found are very nearly equal, as would be expected from the crystal structure of magnesium, a hexagonal close packed structure of *spheres* The compression found now is about 0 5 per cent greater in the direction parallel to the hexagonal axis than at right angles.

Ammonium Dihydrogen Phosphate ("*A D P*") This I owe to the kindness of Dr. Hans Jaffe of the Brush Development Co, the results are shown in Table II. It will be noticed that the

TABLE II

AMMONIUM DIHYDROGEN PHOSPHATE

Pressure kg/cm²	Length ‖ optic axis	Length ⊥ optic axis	Volume
0	1 00000	1 00000	1 00000
2,500	99542	99795	99135
5,000	99104	99604	98322
10,000	98267	99253	96405
15,000	97511	98944	95462
20,000	96818	98663	94247
25,000	96170	98389	93097
30,000	95557	98142	92042

compression is somewhat twice as great parallel to the optic axis as at right angles The mean deviations of single readings from smooth curves were 0 12 per cent for the parallel direction and 0 65 per cent perpendicular The greater irregularity perpendicular to the axis corresponds to the smaller compressibility

Primary Potassium Phosphate ("*P K*") The material was furnished by Dr. Jaffe

The results are shown in Table III In the

TABLE III

PRIMARY POTASSIUM PHOSPHATE

Pressure kg/cm²	Length		Volume
	a direction	*c* direction	
0	1 00000	1 00000	1 00000
2 500	99688	99734	99112
5 000	99405	99475	98295
10,000	98896	98976	96802
15 000	98440	98487	95438
20 000	98018	98033	94182
25 000	97619	97004	93068
30,000	97291	97212	92015

"*a*" direction the average deviation of a single reading from a smooth curve was 0 41 per cent, and in the "*c*" direction 0 47 per cent Compared with ammonium dihydrogen phosphate the overall cubic compression is very nearly the same, but the linear compression does not follow the same pattern, being very nearly the same for the two directions for P K , whereas there was a difference by a factor of two for A D P There seem to be no previous measurements on either of these materials for comparison

$LiNa_3Cr_2O_76H_2O$ This material I owe to the kindness of Dr S O Morgan of the Bell Telephone Laboratories

The results are shown in Table IV The com-

TABLE IV

$LiNa_3Cr_2O_76H_2O$

Pressure kg/cm²	Length		Volume
	x direction	*z* direction	
0	1 00000	1 00000	1 00000
2,500	99696	99698	99095
5 000	99400	99446	98256
10,000	98832	98975	96676
15 000	98330	98540	95216
20,000	97804	98141	93882
25,000	97315	97786	92604
30,000	96849	97446	91400

pression in the *z* direction is about 20 per cent less than at right angles The mean deviation of a single reading from a smooth curve was 0 18 per cent for the *x* direction, and 0 25 per cent for *z* There are no previously published measurements for comparison The 40,000 apparatus gave for the volume decrement at 30,000 0 0885 against 0 0860 calculated above

Rubidium Tartrate The material was supplied by Dr Morgan

The results are given in Table V The com-

TABLE V

RUBIDIUM TARTRATE

Pressure kg/cm²	Length		Volume
	x direction	*z* direction	
0	1 00000	1 00000	1 00000
2 500	99569	99821	98965
5,000	99151	99671	97985
10 000	98362	99389	96162
15,000	97658	99144	94552
20,000	96992	98949	93090
25 000	96390	98776	91772
30 000	95858	98625	90624

pressibility in the *z* direction is only one third as great as at right angles The mean deviation of a single reading from a smooth curve was 0 25 per cent for the *x* direction, and 0 6 per cent for *z* The only previous measurements for comparison are those of the volume decrement with the 40,000 apparatus This apparatus gave for the volume decrement at 30,000 0 1014, against 0 0938 above from the linear compressions The discrepancy is larger than usual

Dextrose Sodium Chloride The material was supplied by Dr Morgan

The results are given in Table VI The com-

TABLE VI

DEXTROSE SODIUM CHLORIDE

Pressure kg/cm²	Length		Volume
	x direction	*z* direction	
0	1 00000	1 00000	1 00000
2 500	99494	99714	98710
5 000	98972	99445	97410
10,000	98028	98911	95048
15,000	97339	98427	93260
20 000	96648	98000	91540
25,000	96037	97557	89974
30,000	95443	97172	88516

pressibility in the *z* direction is roughly one half that at right angles In the *z* direction there is an abnormal episode between 17,000 and 25,000, the compressibility dropping with pressure at an abnormally high rate at the beginning of the interval Since all the experimental points consistently indicated the same thing it seems

probable that the abnormality is real, and it was therefore not smoothed out in the table This abnormality does not seem to fall under the conventional classifications as transition of the second or higher order

The mean deviation of a single reading from a smooth curve was 0 73 per cent in the r direction and 0 26 in z The only previous measurements for comparison are with the 40,000 apparatus This gave for the volume decrement at 30,000 0 1178 against 0 1148 above

Dextrose Sodium Iodide The material was furnished by Dr. Morgan

The results are given in Table VII The

TABLE VII

DEXTROSE SODIUM IODIDE

Pressure kg/cm²	Length		Volume
	x direction	z direction	
0	1 00000	1 00000	1 00000
2 500	99478	99612	98570
5,000	99008	99240	97282
10 000	98172	98532	94964
15,000	97434	97865	92907
20 000	96791	97293	91146
25,000	96194	96767	89544
30,000	95692	96286	88166

average deviation of a single reading from a smooth curve was 0 08 per cent for the x direction and 0 24 for z The volume decrement given by the 40,000 apparatus at 30,000 was 0 1196 against 0 1183 above It is to be noticed that the compressibilities in the two directions are much more nearly equal for dextrose sodium iodide than they are for the corresponding chloride The volume decrement of the iodide is greater by a small amount A difference in this direction would be expected on general grounds as a result of replacing chlorine with iodine

$NiSO_4 6H_2O$ This was supplied by Dr Morgan

The behavior in the z direction up to 30,000 proved to be entirely normal In the direction at right angles, however, there is a very marked anomaly in the neighborhood of 20,000, as shown in Figure 1 Below 20,000 the length decreases nearly linearly with pressure with a mean compressibility only about 40 per cent of that in the z direction. Near 20,000 there is a very rapid increase of compressibility in a narrow pressure interval, the maximum compressibility attained being approximately 20 fold the original Between 20,000 and 30,000 the relation between length in the x direction and pressure is very far

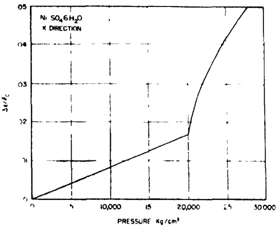

FIGURE 1 The relative change of length perpendicular to the axis of $NiSO_4 6H_2O$ as a function of pressure

from linear, the compressibility at 30,000 having dropped to approximately one third that at 20,000

Four different set-ups with four different specimens were made in the x direction Two of the specimens were cut at right angles to each other, both in the plane perpendicular to z, in order to check whether any triaxiality developed above the transition point No evidence for this was found The behavior of these four samples differed slightly and beyond the errors of measurement The pressure of discontinuity was 19,320, 19,700, 20,000 and 20,050 for the four specimens respectively The maximum difference in the changes of length was about 2 per cent The results given in the table are a rough average for the four directions, taking the pressure of discontinuity as 20,000 and throwing the most weight above the transition on the one specimen which was taken up to the full 30,000

If pressure readings are taken close together in the region of the anomaly the sharp discontinuity disappears, and there appears only a region of very rapidly varying curvature In Figure 2 the fine detail is shown in the neighborhood of the anomaly The points in this diagram were taken with decreasing pressure after the full 30,000 had been reached This excursion to the maximum produced an irreversible permanent fractional change of length when 20,000 was recovered of 0 0004

The final results, with the fine detail in the region of anomaly smoothed over, are shown in Table VIII In the z direction the average

TABLE VIII

$NiSO_4 6H_2O$

Pressure kg/cm²	Length		Volume
	x direction	z direction	
0	1 00000	1 00000	1 00000
2,500	99828	99491	99148
5,000	99661	99014	98345
10,000	99331	98104	96796
15 000	99005	97291	95365
20,000	98685	96575	94050
22,500	97210	96263	90978
25,000	96284	95991	88990
27,500	95653	95738	87594
30,000	95122	95511	86420

deviation of a single reading from a smooth curve was 0 15 per cent, and in the perpendicular direction (best of the four runs and below the anomaly) was 0.46 per cent.

As usual, the preliminary examination was made in the 40,000 apparatus, and an accelerated increase of compressibility found in the neighborhood of 20,000. However, this had none of the abruptness of the change of linear dimensions. The change of volume at 30,000 given by the 40,000 apparatus was 0 0870 against 0 1358 above The magnitude of the discrepancy is quite without precedent, and is impossible to explain by error The effect must be real, and it must mean that whatever it is that occurs at 20,000 is to a great extent suppressed under the constraints imposed in the 40,000 apparatus, in which pressure fails to be hydrostatic by several hundred kilograms under the best conditions, and by much more under unfavorable conditions of high rigidity in the specimen and large difference of compressibility in different directions. The lat-

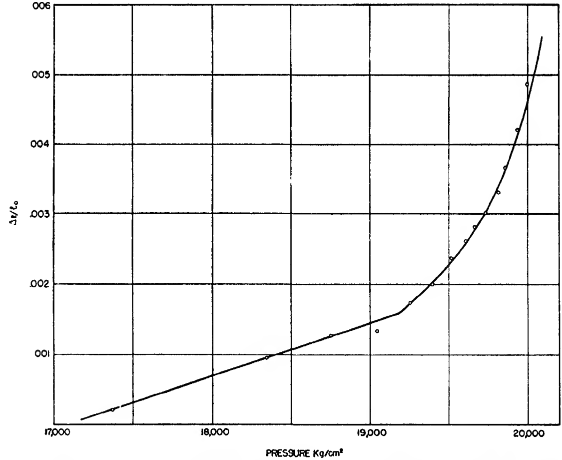

FIGURE 2 Plot on a much enlarged scale of the neighborhood of the break in Figure 1. together with the experimental points obtained with decreasing pressure.

ter condition, at least, is fulfilled by the present substance.

Benzil I owe this to the kind offices of Lt. Paul H Egli, through whom the Naval Research Laboratory supplied it to me. The orientations were kindly identified by Professor C. Frondel of the Department of Mineralogy of Harvard University

Both directions are anomalous, and furthermore the anomalies are not connected in the way demanded by thermodynamics if the stress system is a pure hydrostatic pressure The explanation does not appear, but must be connected in some way with a slight failure of the stress to be hydrostatic The specimen in the piezometer, in order to be sure that all contacts shall be tight and there shall be no back lash, is subjected to a unidirectional compressional stress along the axis in addition to the hydrostatic pressure This stress is of the order of only 0 5 kg/cm². Never before has there been any evidence that this stress plays any role.

Two specimens were used in each direction, and the anomalies repeated The mean deviation of a single point from a smooth curve was 0 24 per cent for the "*a*" direction and 0 25 per cent for "*c*" The anomaly in the *c* direction consists in an abrupt *increase* of length at 22,500 From here the curve follows along parallel to its course before the jump, but on a higher level, until 26,800, when there is an abrupt downward turn in direction, but no discontinuity, until at 28,500 a rough prolongation of the original curve is reached Pressure was not carried beyond this point. On release of pressure the course with increase of pressure was reversibly retraced The experimental points are shown in Figure 3 Thermodynamics, of course, permits only transitions with decrease of volume, so that in the "*a*" direction this anomaly would demand a discontinuous decrease of length large enough to at least compensate for the increase at right angles However, no anomaly whatever was found in the "*a*" direction at 22,500 There is a smaller repeatable and reversible anomaly at 12,500, which consists in a cusp-like increase of compressibility, or at least cusp-like to pressure readings spaced about 2,000 kg/cm² apart This is followed by an inverse anomaly at 25,000, the compressibility becoming discontinuously smaller. This latter anomaly was reversible, but it was not checked by repetition with the second specimen, which was made so long in order to give greater

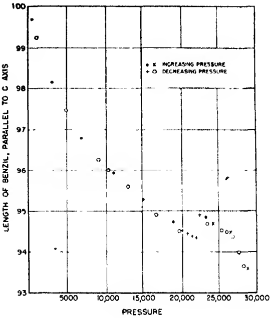

FIGURE 3 The relative change of length perpendicular to the axis of benzil as a function of pressure The increase of length between 20,000 and 25,000 is reversible

sensitiveness that it could not be carried above 25,000 without running beyond the stroke of the lever

These anomalies are reproduced as they were found in Table IX It would be misleading to

TABLE IX
BENZIL

Pressure kg/cm²	Length, *a* direction	Length, *c* direction
0	1 0000	1 0000
2,500	9905	9832
5,000	9833	9731
7 500	9766	
10,000	9705	9598
12,500	9650	
15,000	9569	9513
17,500	9500	
20,000	9438	9446
22,500	9370	9418 / 9470
25,000	9321	9440
26,800		9423
27,500	9290	
28 500		9345
30,000	9269	

calculate from the changes of length the volume change, and this column is therefore omitted

Preliminary measurements were made as usual

in the 40,000 apparatus, and no anomalies found at all The change of volume at 30,000 found with it was 0 184, which is not far from what would be computed by taking the changes of length in Table IX at their face value

Sodium Ammonium Tartrate The material was furnished by Dr Morgan

The measurements went smoothly and without episode Two complete sets of measurements were made on this substance with six specimens in all The repetition was made necessary by a confusion of orientations in the first set by which two "y" orientations were measured and no x On the repetition the agreement in the changes of length was exact for the y orientation and within 1 per cent for z The results shown in Table X are those of the second set The mean

TABLE X

SODIUM AMMONIUM TARTRATE

Pressure kg/cm²	Length			Volume
	x direction	y direction	z direction	
0	1 00000	1 00000	1 00000	1 00000
2 500	99332	99752	99622	98712
5 000	98693	99523	99263	97408
10 000	97556	99108	98612	95342
15,000	96575	98739	97994	93444
20 000	95701	98403	97468	91788
25 000	94907	98082	96993	90288
30,000	94281	97784	96564	89028

deviations of single readings from smooth curves for the x, y, and z directions respectively were 0 23, 0 43, and 0 27 per cent The volume decrement at 30,000 obtained with the 40,000 apparatus was 0 1148 against 0 1097 above

Strontium Formate The material was supplied by the Naval Research Laboratory, and the identification of orientations made by Professor Frondel

The results are shown in Table XI The average deviations of single readings from smooth

TABLE XI

STRONTIUM FORMATE

Pressure kg/cm²	Length			Volume
	a direction	b direction	c direction	
0	1 00000	1 00000	1 00000	1 00000
2,500	99670	99802	99617	99092
5 000	99390	99610	99271	98278
10,000	98870	99236	98629	96770
15,000	98387	98886	98024	95368
20,000	97932	98566	97452	94068
25,000	97516	98260	96923	92870
30 000	97148	97965	96426	91764

curves in the a, b, and c directions were 0.42, 1.5, and 0 33 per cent respectively The volume decrement at 30,000 found with the 40,000 apparatus was 0 0858 against 0 0824 above.

Sulfamic Acid The material was supplied by Dr Jaffe, who identified the axis The system of axes adopted is that of Jaeger as quoted by Bryant [7] "According to this system the b axis coincides with the acute bisectrix The c axis coincides with the normal to the optic plane "

TABLE XII

SULFAMIC ACID

Pressure kg/cm²	Length			Volume
	a direction	b direction	c direction	
0	1 00000	1 00000	1 00000	1 00000
2 500	99698	99682	99502	98978
5,000	99433	99402	99195	98046
10 000	98948	98898	98495	96385
15,000	98513	98432	97863	94896
20,000	98114	98007	97295	93558
25,000	97748	97633	96827	92406
30,000	97419	97306	96386	91370

The results are shown in Table XII The average deviations of single readings from smooth curves in the a, b, and c directions were 0 42, 0 36, and 0 36 per cent respectively The volume decrement at 30,000 found with the 40,000 apparatus was 0 0885 against 0 0863 above

HIO_3 The material was supplied by the Naval Research Laboratory and the identification of directions made by Professor Frondel

TABLE XIII

HIO_3

Pressure kg/cm²	Length			Volume
	a direction	b direction	c direction	
0	1 00000	1 00000	1 00000	1 00000
2 500	99789	99481	99625	98900
5 000	99592	98995	99276	97880
10,000	99229	98106	98688	96070
15 000	98894	97349	98034	94382
20,000	98588	96680	97510	92042
25,000	98316	96059	97020	91534
30 000	98068	95549	96560	90482

The results are shown in Table XIII. The average deviations of single readings from smooth curves in the a, b, and c directions were 0.62, 0 24, and 0 62 per cent respectively The volume decrement at 30,000 obtained with the 40,000 apparatus was 0 1015 against 0 0952 above.

$MgSO_4 7H_2O$ This material I owe to the kindness of Mr George C Kennedey, who grew the crystals especially for these measurements from

aqueous solution by the method of slowly lowering the temperature. The work was done at Harvard University. During the war Mr Kennedey had been engaged on similar work for the Navy

Preliminary exploration with the 40,000 apparatus disclosed three transitions, one between 10,000 and 15,000, and two close together and not completely resolved in the neighborhood of 25,000 All these transitions are sluggish, with a wide region of indifference The present measurements were of necessity restricted to pressures below 10,000 Even in this range the results were more irregular than usual

TABLE XIV

$MgSO_4 7H_2O$

Pressure kg/cm²	Length			Volume
	a direction	*b* direction	*c* direction	
0	1 00000	1 00000	1 00000	1 00000
2,500	99666	99563	99649	98880
5,000	99348	99131	99341	97834
7,500	99042	98705	99070	96850
10,000	98750	98286	98826	95918

The results are shown in Table XIV The average deviation of a single reading from a smooth curve was 1 1, 0 75, and 1 2 per cent respectively for the *a*, *b*, and *c* directions The change of volume at 10,000 found with the 40,000 apparatus was 0 0445 against 0 0408 above The discrepancy is largely due to uncertainty in the 40,000 measurements due to sluggishness of the transitions

Morpholine Hydrogen Tartrate The material was supplied by Dr Morgan

TABLE XV

MORPHOLINE HYDROGEN TARTRATE

Pressure kg/cm²	Length			Volume
	x direction	*y* direction	*z* direction	
0	1 00000	1 00000	1 00000	1 00000
2,500	99191	99780	99346	98324
5,000	98521	99585	98378	96516
10,000	97345	99203	97202	93866
15,000	96402	98856	96289	91764
20,000	95573	98532	95555	89982
25,000	94850	98229	94888	88408
30,000	94191	97954	94384	87080

The results are shown in Table XV The mean deviation of a single reading from a smooth curve for the *x*, *y*, and *z*, directions respectively was 0.10, 0.46 and 0 15 per cent The voulme decrement at 30,000 found with the 40,000 apparatus was 0.1228 against 0.1292 above The measurements with this material went smoothly in all respects with a minimum of the irregularities which some of the other materials show I think that many of these irregularities are not instrumental, but are genuinely associated with the materials

Rochelle Salts The material was supplied by Dr Jaffe Two completely independent sets of measurements were made with material from two different crystals On the first determination there was apparently a confusion with regard to the "*b*" orientation, this apparently having been replaced by the *a* orientation Repetition of the results was therefore demanded Dr Jaffe kindly provided a second batch of material with orientations marked, and Professor Frondel made an independent confirmation of the orientations

TABLE XVI

ROCHELLE SALTS

Pressure kg/cm²	Length			Volume
	a direction	*b* direction	*c* direction	
0	1 00000	1 00000	1 00000	1 00000
2 500	99382	99743	99613	98742
5,000	98789	99505	99260	97570
10,000	97773	99043	98626	95504
15,000	96868	98628	98079	93704
20,000	96032	98270	97588	92096
25 000	95270	97975	97151	90684
30,000	94597	97722	96728	89420

The results for the second specimen are shown in Table XVI The decrements of length in the *a* and *c* directions given by the first specimen agreed within about one per cent with the corresponding values for the second The mean deviations of a single reading from a smooth curve for the *a*, *b*, and *c*, directions were respectively 0.28, 1,23, and 0 42 per cent respectively

The confirmation of the results in Table XVI by the volume decrements measured independently with the 40,000 apparatus was closer than usual The volume decrement at 30,000 given by the latter was 0 1053 against 0 1058 of the table In addition to this, comparison may be made with my own former measurements[8] of the change of length up to 12,000 kg/cm² The decrements of length at 10,000 kg/cm² formerly found in the *a*, *b*, and *c* directions respectively were 0 01029, 0 02217, and 0.01320 against 0.02227, 0 00957, and 0 01374 now given in Table XVI It would appear that *a* and *b* orientations in the former work must have been

inverted, a probability which is strengthened by inspection of the original note books

There seem to be no other measurements under hydrostatic pressure for comparison There have, however, been a number of measurements of the elastic constants at atmospheric pressure from which the initial compressibilities may be computed A summary of these may be found in Cady's book on Piezoelectricity. It would appear from an inspection of this work that none of the measurements of elastic constants are accurate enough to allow computations of the linear compressibilities of any reliability In this calculation the errors conspire in a particularly unfavorable way For instance, the linear compressibility in the *b* direction calculated with that combination of constants which is recommended as best turns out to be negative, a conclusion which can be rejected with confidence on the basis of the direct measurements In general, the error in measuring the linear compressibilities appears to be much less than that in measuring the other constants, so that in calculating the other constants adjustments should be made so that they will yield the measured linear compressibilities

Discussion

This discussion will be concerned with several purely formal matters with the object of giving a better descriptive grasp of the results, and will not attempt at all to assess their physical significance.

In the first place, the magnitude of the mean compression is of interest. As a measure of this we may take the volume decrement under 30,000 Omitting the only metal in the above list, magnesium, and confining attention to the salts, the smallest volume decrement is for Ammonium Dihydrogen Phosphate, 0 0796, and the largest for $NiSO_4 6H_2O$, 0 1358 This is variation by less than a factor of two, which is comparatively small in view of the known variation by a factor of 300 between the least and most compressible elements, carbon and caesium In speculating on the reason for this it is to be remembered that all the substances measured here have this in common, that they are soluble in water and were grown in single crystal form from aqueous solution.

The degree of anisotropy of the crystal with regard to hydrostatic compression is of interest This may be arbitrarily defined as the ratio of the decrement of linear dimension in the direction in which it is greatest to that in the direction in

TABLE XVII

SUMMARY

Substance	∥ axis, *c*, or *z*			⊥ axis, *a* or *x*			⊥ axis, *b*, or *y*			Volume			Anisotropy	
	$\left(\frac{\Delta l}{l_0}\right)_{30,000}$	Deviation	Relative Deviation	$\left(\frac{\Delta l}{l_0}\right)_{30,000}$	Deviation	Relative Deviation	$\left(\frac{\Delta l}{l_0}\right)_{30,000}$	Deviation	Relative Deviation	$\left(\frac{\Delta V}{V_0}\right)_{30,000}$	Deviation	Relative Deviation	Magnitude	Axes of greatest and least compression
Magnesium	02452	0370	1 51	02388	0377	1 58				07056	0435	0 62	1 026	*c*, *a*
Ammonium Dihydrogen Phosphate	04443	0603	1 36	01858	0684	3 68				07958	0702	0 88	2 39	*c*, *a*
Primary Potassium Phosphate	02788	0427	1 53	02709	0761	2 81				07985	0714	0 89	1 027	*c*, *a*
$LiNa_3Cr_2O_7 6H_2O$	02554	0717	2 80	03151	0397	1 26				08600	0563	0 65	1 234	*a*, *c*
Rubidium Tartrate	01375	1084	7 89	04142	0659	1 59				09376	0811	0 86	3 01	*a* *c*
Dextrose Sodium Chloride	02828	0562	1 99	04557	0840	1 84				11484	0867	0 76	1 61	*a*, *c*
Dextrose Sodium Iodide	03714	0748	2 01	04308	0957	2 22				11834	0993	0 84	1 163	*a*, *c*
$NiSO_4 6H_2O$	04489	1035	2 30	04878	− 296	−6 07				13580	− 159	−1 17	1 086	*a* *c*
Sodium Ammonium Tartrate	03436	0837	2 43	05716	0992	1 73	02216	0689	3 12	10972	0977	0 89	2 58	*a*, *b*
Strontium Formate	03574	0528	1 48	02857	0648	2 27	02035	0478	2 35	08236	0624	0 76	1 755	*c*, *b*
Sulfamic Acid	03614	0913	2 52	02581	0763	2 95	02694	0822	3 05	08630	0914	1 06	1 40	*c* *a*
HIO_3	03440	0716	2 08	01932	0725	3 75	04451	0958	2 15	09518	0902	0 95	2 30	*b*, *a*
Morpholine Hydrogen Tartrate	05616	1606	2 85	05809	1193	2 05	02046	0592	2 89	12920	1374	1 06	2 84	*a*, *b*
Rochelle Salts	03272	0865	2 64	05403	0797	1 47	02278	1024	4 50	10580	0998	0 94	2 37	*a*, *b*

which it is least. This is shown in Table XVII. Among the crystals with rotational symmetry requiring two constants, three are more compressible along the axis, and four at right angles The anisotropy varies from 3.01 for rubidium tartrate to 1.029 for Primary Potassium Phosphate and 1.026 for magnesium. Among the orthorhombic crystals requiring three constants three are most compressible along the *c* axis, two along *a* and one along *b*. The anisotropy in this group varies from 2.84 for morpholine hydrogen tartrate to 1.398 for sulfamic acid The anisotropy shown by this group of crystals is not large when it is considered that zinc is eight times more compressible along the axis than at right angles, and tellurium has a negative ratio in the two directions.

We next consider the deviations from linearity, or the curvature in the relation between pressure and distortion This may be arbitrarily defined as the ratio of the difference between the actual distortion at 15,000 and the distortion which would have occurred at 15,000 if the relation were linear up to 30,000, to the distortion at 30,000 Expressed analytically for change of length, this is

$$\text{Deviation} = \frac{\Delta l_{15,000} - \frac{1}{2}\Delta l_{30,0000}}{\Delta l_{30,000}}$$

Previous experience would lead to the expectation that the "deviation" so defined would be larger the larger the absolute value of the distortion, or that deviation divided by the decrement of length at 30,000 would be roughly of the order of magnitude of unity and would not vary greatly from substance to substance I have already shown that when the volume change up to 12,000 kg/cm² is represented by the two constant formula $\Delta V/V_0 = -ap + bp^2$, the dimensionless combination b/a^2 varies in the general neighborhood of unity

In Table XVII are given the changes of dimensions at 30,000, the deviations, and the ratio of the deviation to the change at 30,000 This latter we may define as the "relative deviation." The deviation varies from a maximum of 0.161 for morpholine hydrogen tartrate to a minimum among the salts of 0 0397 for $LiNa_3Cr_2O_7 6H_2O$ and 0.0372 for magnesium. No correlation is obvious between deviation and direction in the crystal The relative deviation, omitting for the moment rubidium tartrate, varies from 3.75 to 1 36 for changes of length and from 1 06 to 0.616 for changes of volume The expectation is borne out that the relative deviation fluctuates in the general neighborhood of unity Its range of fluctuation is definitely less than the range of fluctuation of the deviation itself, but the difference is not overwhelming. The deviation for the volume is in general not far from the deviation for the length, which means that the relative deviation for the volume is of the order of one third the relative deviation for length. There seems no general correlation between the relative deviation and direction.

Rubidium Tartrate is clearly an exception. Along the axis the compressibility is by far the least of any substance in the table, whereas at the same time its deviation from linearity is among the highest and its relative deviation is entirely out of line, being 7 89 against a next nearest figure 3.75 One might be tempted to suspect an approach to a transition of the second kind, but as a matter of fact the abnormally high curvature is distributed uniformly over the whole pressure range

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THE SCATTERING OF HIGH VELOCITY NEUTRAL PARTICLES. I.

By I. Amdur, C F Glick and H. Pearlman

(Contribution from the Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts)

THE SCATTERING OF HIGH VELOCITY NEUTRAL PARTICLES. I.

By I. Amdur, C. F. Glick,* and H. Pearlman†

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TABLE OF CONTENTS

A. Introduction

The estimation of the interaction energies between atoms and molecules as functions of their separation distances is of fundamental importance for a complete understanding of numerous chemical and physical problems. Among the many properties which can be calculated from theory if the mutual energy of interaction is known are: compressibility and thermal expansion of solids and liquids, and transport properties (viscosity, thermal conductivity, and diffusion coefficients) of gases. To date, much of the information on intermolecular interactions has been derived from experimental measurements of these properties and their temperature coefficients. The results have not been completely satisfactory, however, for several reasons. First, the existence of intermolecular forces results, in some cases, in producing perturbations of the properties of an ideal system of forceless molecules, as, for example, the pressure-volume-temperature relations of a mass of a gas. When this perturbation is not very large, it is very difficult to estimate interaction potentials from experimental measurements with satisfactory accuracy Second, the theoretical treatment of the experimentally measured property is often so complicated that drastic simplification of the molecular model must be made before it is possible to obtain numerical values for the interaction potential. As a result, the conclusions often bear little resemblance to reality, as in the case of molecular models of mass points possessing only repulsive forces which are frequently assumed in order to deduce interaction potentials from experimental values of the coefficients of viscosity, thermal conductivity, and diffusion of gases at relatively low temperatures. Finally, the limited temperature range over which it is possible to make measurements results, in many cases, in values of the mutual potential energy which are valid over very narrow ranges of the separation distance

A more direct approach to the experimental determination of intermolecular interactions would seem to lie in attempts to study actual collisions between molecules. If the masses, initial speeds, final speeds, and direction of scattering are known for a colliding system, it is possible to determine the potential energy of interaction at the distance of closest approach of the two particles.[1] This method of attack has the advantage that the effects of molecular interactions are not reflected in small changes in compressibility, viscosity, or similar properties characteristic of large aggregates of molecules, but directly in the change in speed and direction of the interacting molecules. As a consequence, the results of scattering experiments tend to lead directly to the desired information about molecular interactions. However, the experimental difficulties are great since well defined, unidirec-

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[1] E. H. Kennard, *Kinetic Theory of Gases* (McGraw-Hill Book Company, Inc., New York, 1938), pp. 115–134.

tional beams of collision free neutral particles and accurate methods for detecting such beams are required. The discovery of Dunoyer[2] that thermal velocity molecular beams could be produced by methods similar to those used in collimating light showed that an experimental study of the physical characteristics of single collisions was plausible The techniques of the molecular beam method were brilliantly developed by Stern and his co-workers[3] between 1923 and 1933 so that the thermal velocity beam is now a well established, accurate research tool.

The scattering of molecular beams with ordinary thermal velocities provides information concerning intermolecular forces at relatively large separation distances where forces of attraction usually predominate over forces of repulsion.[4] Scattering experiments of this type are of secondary interest to the authors for two reasons. First, other types of measurements already mentioned, although less satisfactory, are capable of supplying information in the same general range of interaction distances Second, quantum theory calculations have been reasonably successful in predicting the magnitude of attractive forces, particularly for non-polar molecules. On the other hand, at small separation distances where repulsive forces predominate, theoretical calculations are not generally successful or possible and laboratory experiments on large aggregates of molecules are not feasible since temperatures are required in excess of the limit obtainable Since the scattering of neutral particles with controlled high velocities appears to offer a unique approach to the study of repulsive interaction forces at small distances, the authors have endeavored to develop apparatus and techniques of the same high quality as those used in ordinary thermal velocity beam research

B Previous Contributions

Beams of fast neutral atoms were first produced by Oliphant,[5] who found a beam of neutral, metastable ^3S helium atoms while studying beams of helium ions. Beeck[6] produced a beam of fast argon atoms by the process of "umladung" which involves the collision of an accelerated ion with a slow atom and results in a transfer of kinetic energy to yield a fast neutral atom and a slow ion. This method was further investigated by Kallman and his co-workers,[7] and later used by Rostagni[8] to produce beams of fast hydrogen, argon and neon.

Amdur and Pearlman,[9] using a device similar to the proton source of Lamar and Luhr,[10] introduced the use of high velocity neutral beams for the determination of repulsive intermolecular potentials from measured total collision cross-sections. They scattered fast hydrogen atoms in room temperature hydrogen gas and fast helium atoms in room temperature helium gas and were able to evaluate interaction potentials from their results. For the system, H—H_2[11], the repulsive potential energy may be expressed as

$$V(r) = 0.846 \times 10^{-10} \exp(-24.9r^2) + 0.211 \times 10^{-10} \exp(-2.40r^2) \text{ erg} \quad (1)$$

for values of r, the distance between mass points representing the hydrogen atom and the hydrogen molecule, in the range 0.28–0.70A. The corresponding relation for the system He—He[12] is

$$V(r) = 11.3 \times 10^{-10} \exp(-4.63r^{\frac{1}{2}}) \text{ erg} \quad (2)$$

for values of r in the range 0.55–1.05A.

C. Present Contribution

The original apparatus of Amdur and Pearlman had several limitations which restricted the scope of the experiments which could be performed First, the detector was stationary in the beam axis so that it was not possible to measure the angular distribution of scattering, but only total collision cross-sections Under such conditions, only one point on the potential energy curve can be obtained from a cross-section value at a given

[2] L Dunoyer, Compt rend *152*, 594 (1911), Le Radium *8*, 142 (1911).

[3] See numerous references in R G J Fraser, *Molecular Beams* (Methuen and Company, Ltd, London, 1937) and *Molecular Rays* (The Macmillan Company, New York, 1931).

[4] H. S W. Massey and C. B O. Mohr, Proc Roy. Soc *A144*, 188 (1934). H S W. Massey and R. A. Buckingham, Nature *138*, 77 (1936).

[5] M. L. E. Oliphant, Proc Roy. Soc. *A124*, 228 (1929).

[6] O Beeck, Ann der Phys (5) *19*, 121 (1934).

[7] H Kallman and B Rosen, Zeit. für Phys. *61*, 61 (1930). H Kallman, W. Lasareff, and B. Rosen, Zeit. für Phys. *76*, 213 (1932).

[8] A. Rostagni, Zeit. für Phys. *88*, 55 (1934).

[9] I Amdur and H. Pearlman, J. Chem. Phys. *8*, 7 (1940).

[10] E S Lamar and O Luhr. Phys Rev. *46*, 87 (1934).

[11] I Amdur, J. Chem. Phys. *11*, 157 (1943).

[12] I Amdur and H. Pearlman, J. Chem. Phys. *9*, 503 (1941).

beam velocity, in contrast to a series of points derivable from angular intensity measurements of a scattered beam at the same velocity. Second, the long scattering path, about 8 5 cm., introduced uncertainties in the estimation of the angular aperture subtended by the detector which were reflected in the final potential energy relations Finally, it was necessary to make relatively large corrections to the observed scattered beam intensities because of the large pressure dependence of the detector which was not isolated from the scattering gas. It was therefore considered desirable to design a second scattering unit which would (1) permit accurately measurable travel of the detector with respect to the beam axis and (2) localize the scattering gas in a narrow chamber to simplify the estimation of the detector aperture and to permit the detector to be in a highly evacuated region at all times. In addition to eliminating restrictive features of the first apparatus, the second unit was designed to incorporate significant improvements among which were elimination of sources of mercury vapor by using a rapid oil diffusion pump and substituting a thermocouple gage and an ionization gage for the previous McLeod gages, and the use of a self-contained Pirani gage to measure the pressure of gas in the scattering chamber. It is the primary purpose of the present paper to describe this new apparatus and to indicate its potentialities by showing its performance characteristics. The authors feel that the preliminary results obtained show that their first objective has been obtained, namely, the development of an apparatus of the same quality as those used in thermal velocity beam research.

The beam of high velocity neutral particles is made in a manner analogous to that used by Lamar and Luhr[10] for producing high velocity protons A low voltage arc (20–60 volts, 0.5–1.5 amperes) is struck between a filament, at ground potential, and an anode in gas at 0 10–0 50 mm. pressure. · Positive ions (0 10–0 30 ampere), produced primarily by electron collisions in the gas, are drawn to the cathode which is at a negative potential of 50–200 volts. Some of the positive ions (1 0–10.0 milliamperes) are drawn through a hemispherical nickel grid of 40 mesh screen mounted over an aperture in the cathode, and focused on the atom gun, an electrode with a small central canal. The negative potential on the atom gun may be varied from 200 to 2000 volts and some of the focused positive ions are neutralized in the canal of the gun, either at grazing incidence with its walls, or without actual physical contact.[13] The neutralization occurs without appreciable loss of kinetic energy, so that the beam emerging from the canal is a mixture of high velocity neutral atoms and positive ions which escaped neutralization. These ions are repelled by the top surface of the scattering chamber which acts as an ion mirror since it is at ground potential Thus, the only high velocity particles entering the scattering chamber are neutral, accelerated gas molecules.

1. *Structural Details of the Apparatus*

The essential details of the present apparatus, with the exception of the electrical circuits, are shown in Figure 1. The arc section consists of two concentric brass tubes soldered to brass flanges at top and bottom Hard solder is used except for the bottom joint of the outer tube, which is soft soldered The section is provided with inlet and outlet tubes for circulating cooling water through the annular space, a ½ inch cathode lead tube, and a 1 inch tube which leads to the scattering section through the large valve, 13. The portion of the 1 inch tube adjacent to the arc section contains an inlet tube for introducing gas and a connection, 12, for a thermocouple gage which measures the pressure in this section

The arc section is fastened to the scattering section by 16 bolts which thread into the top flange of the scattering section The junction of the two sections is made vacuum tight by a lead gasket, 0 040″ thick. The filament adjuster, 1, is fastened to the arc section by a split steel plate and a similar arrangement of bolts and gasket.

It has been previously found[9] that the beam intensity frequently varied with the distance between the filament, 4, and the hemispherical grid, 5. A filament adjuster was therefore included in the present apparatus to permit accurate adjustment and measurement of the filament position. The adjuster is housed in a 5 inch length of brass tubing soft soldered into a brass flange Vertical motion in vacuum is obtained by turning the knurled graduated knob at the top of the adjuster, since the drive shaft is pinned to a vacuum tight plate at the lower, free end of a bellows whose upper, fixed end is soldered peripherally to the inside of the housing Eyelets, consisting of metal to glass seals, are used to bring leads from the filaments and anode, 2, through

[13] M L E Oliphant and P. B. Moon, Proc Roy Soc. *A127*, 388 (1930).

the bottom plate A radiation baffle is fastened below the plate to prevent the eyelets from being short circuited by evaporated and sputtered metal from the arc The filament leads, protected from shorting to the anode by quartz sleeves, pass freely through holes in the anode as the bellows is compressed or extended. The required freedom of motion in this region with respect to the fixed anode is supplied by a phosphor bronze spring which serves as the anode lead. The adjuster permits about 1 inch of filament travel from a zero position about ½ inch above the grid. A metal index, fastened to the top of the drive shaft, indicates relative filament heights to

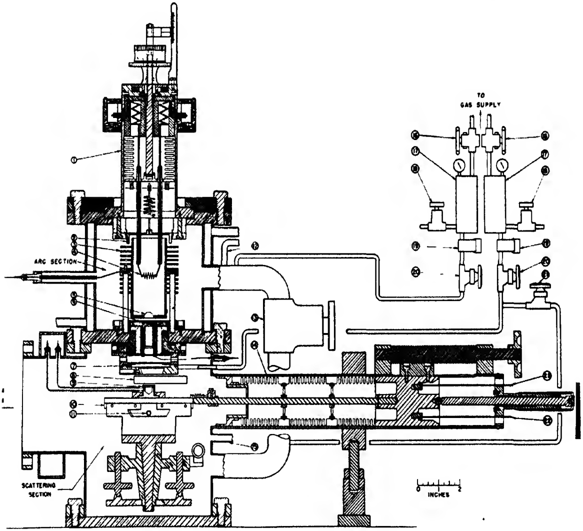

FIGURE 1 Details of high velocity molecular beam apparatus

1 Filament adjuster
2 Anode
3 Cathode
4. Filament
5. Grid
6. Atom gun
7. Scattering chamber
8 Condensers
9 Detector
10. Longitudinal slide
11 Transverse slide
12 Thermocouple gage connection
13 Arc section by-pass valve
14 Longitudinal slide drive
15 Ionization gage connection
16 Gas supply shut-off valves
17 Ballast tanks
18 Gas supply pump-out valves
19. Throttle valves
20. Low pressure shut-off valves
21 Scattering chamber by-pass valve
22. Counterweight cables

twentieths of an inch on a graduated vertical standard; measurements to thousandths of an inch are read from the graduated drum of the knurled knob

The apparatus has been designed to permit measurements of positive ion scattering by placing the atom gun at ground potential, the filament at variable positive potential, and the anode and cathode at appropriate potentials with respect to the filament, thereby eliminating the ion mirror action of the grounded scattering chamber. It is therefore necessary to provide for both flexibility and high voltage insulation of the filament and anode leads in the section of the filament adjuster above the vacuum tight bellows plate. This is accomplished by fastening coiled, stranded lead wires to the ends of the rigid leads from the filament and anode and encasing each of the three coils in wells drilled in a Lucite plastic cylinder which fits inside the adjuster housing and rests on the top bellows convolution A Lucite disk covers the cylinder making it impossible for any portion of a coil to leave its well since the point at which the lower end of each coil is fastened to its rigid lead never leaves the well. At the top of the Lucite cylinder each stranded lead wire is held by the disk in a groove which leads into holes in the cylinder walls. The wire is fed through these holes and out through openings in the brass housing. Bakelite bushings prevent the leads from shorting to the brass walls. A Bakelite annular ring, suitably partitioned to segregate the three leads, is anchored to the housing and receives a conduit carrying leads from the filament and anode power sources Soldered connections are made inside the partitions of the annular ring simply by removing the top cover.

The most suitable filaments were found to be standard oxide coated filaments used in type 866A mercury rectifier tubes. The filaments were kindly supplied without charge by the Radio Corporation of America

The cathode, 3, was machined from aluminum and provided with cooling fins, one of which is $\frac{5}{16}''$ thick as compared with $\frac{1}{16}''$ for the remainder. The cathode is supported about $\frac{1}{16}''$ above the atom gun by three $\frac{1}{4}''$ diameter Isolantite ceramic rods. These pass through holes, spaced 120° apart, drilled through the bottom four fins and seat, at their upper ends, in the thick fin, while their lower ends rest in the floor of the arc section. The thick cathode fin also contains a set screw for fastening the cathode lead. The hemispherical screen grid, 5, which focuses positive ions on the atom gun, 6, is fastened over a $\frac{1}{2}''$ opening in the bottom of the cathode by a close fitting aluminum cap with a $\frac{1}{2}''$ center hole.

The anode is a cap machined from aluminum of size sufficient to permit at least $\frac{1}{16}''$ clearance between any point on it and any point on the cathode It is provided with a ledge and peripheral boss to locate it between two rings of lava which are fastened to the flange of the filament adjuster. The arrangement insures proper alignment of the anode relative to the cathode A second boss toward the center of the anode is tapped to receive the phosphor bronze spring lead.

The aluminum atom gun, shown in greater detail in Figure 2A, is $1\frac{3}{4}''$ in diameter across the face and $1\frac{3}{8}''$ long. The central canal is 0 020″ in diameter and 0 120″ long and is well rounded on the top to reduce discharge to the cathode. An insulating bushing, machined from a low vapor pressure plastic, Teflon, separates the atom gun from the aluminum insert which threads into the lower flange of the arc section and supports the scattering chamber, 7 The high voltage lead enters through a metal-glass seal in the scattering section and is connected to a brass washer held by spring contact against the bottom of the atom gun A glass ring, fastened to the bottom of the aluminum insert, holds and insulates the high voltage washer contact. Pressure against the washer is obtained by forcing the atom gun down against the tension of the springs with a lava ring which bears on the face of the gun. The under surface of the gun face and the upper and under surfaces of the bushing into which the gun fits are made as smooth as possible to minimize leakage of gas from the arc section to the scattering section

The scattering chamber consists of two parts which are soldered together The upper section is cylindrical in shape and contains a 0.020″ entrance hole for the beam Twenty $\frac{1}{4}''$ holes, equally spaced, have been drilled around the periphery of this section to permit rapid pumping of the region between the atom gun and the entrance to the scattering chamber. Two of the holes have been converted into a slot to permit passage of a glass vane, $\frac{1}{4}''$ wide, $1\frac{1}{2}''$ long and 1/32″ thick, which serves as a shutter to cut out the beam. The vane is moved in and out of the beam by a helical drive bellows arrangement not shown in the figure. The bottom section of the scattering chamber is $2\frac{3}{4}''$ square with an annular ring $2\frac{1}{2}''$ O. D. and $\frac{1}{4}''$ wide which telescopes

into the upper section. The bottom section contains the exit slot for the beam and two adjustable jaws which cover the slot to form a long, narrow slit. The important dimensions of the scattering chamber are shown in Figure 2A and in Figure 2B in which the bottom section of the scattering chamber has been turned through 90° to show the manner in which the jaws close over the exit

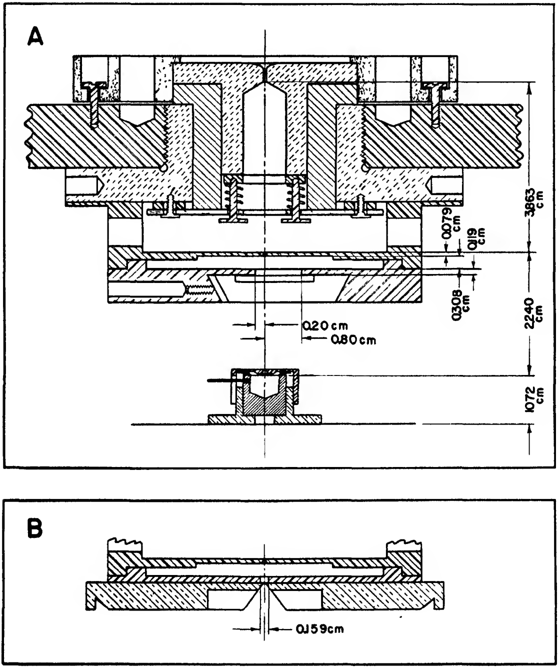

FIGURE 2. Details of atom gun, scattering chamber, and detector. A. Critical dimensions and distance relations. B. Scattering chamber exit slit jaws.

slot to form the exit slit The pressure of the scattering gas in the region between the upper and lower sections of the scattering chamber is measured with a self-contained, compensated Pirani gage which also forms part of a circuit for measuring the temperature of the scattering gas. The details of this gage will be described under performance characteristics of the apparatus

Two condenser plates, 8, sweep out of the beam any electrons or positive ions resulting from ionization action of high speed neutrals, as well as electrons emitted by metallic surfaces upon being struck by high energy particles The plates are made of chromium plated brass and are 2½" long, ⅜" wide, and 1/32" thick. They are so placed that the separation distance between the inside faces, 0 080", is symmetrical about the beam, while the length is asymmetrically distributed about the beam, about ¾" on the side toward the vacuum system. Potential differences up to 2000 volts may be impressed across the condensers

The neutral beam intensity is measured by the detector, 9, (to be described later) which is mounted on a movable slide, 10. Longitudinal motion of the detector, in the direction parallel to the length of the exit slit, is obtained with a worm drive bellows arrangement, 14, which permits 2" of travel, 0 3" on the vacuum system side, and 1 7" on the worm drive side of the beam axis A micrometer measures the position of a hardened steel ball spun into the center of the movable piston actuated by the worm drive, thereby determining relative longitudinal positions of the detector to 0 0005". A 50 pound counterweight is suspended from stranded brass cables, 22, over a pulley system, to balance the inward thrust of the atmosphere and permit easy motion of the worm drive Transverse motion of the detector, in the direction perpendicular to the length of the exit slit, is obtained with a small micrometer bellows drive whose shaft is attached to the other movable slide, 11, of the detector carriage This arrangement permits transverse motion of the detector of about 0 040" on either side of the beam axis and enables relative positions to be determined to 0.0005"

A 12 bolt, lead gasketed, flange combination connects the scattering section to the vacuum system consisting of a 4 inch oil fractionating diffusion pump, equipped with a water cooled baffle and backed with a Hypervac-20 forepump The diffusion pump is protected against failure of its cooling system or excessive rise in forepressure[14] The pumping speed of the vacuum system is estimated at 100 liters of air per second (the decrease from 275 liters per second, the nominal rating of the diffusion pump, is due to the presence of the baffle) and is sufficient to maintain a pressure of 6 x 10^{-5} mm. of helium in the scattering section with a helium pressure of 0 1 mm. in the arc section A tube, 15, leads directly from the scattering section to an ionization gage which reads the low pressures in this section of the apparatus

There are several features of the scattering section not shown in Figure 1 or previously described. These include six metal-glass seals for taking out the electrical leads from the scattering chamber Pirani gage network and the condensers and a Pyrex observation window 2½" in diameter and ⅜" thick which is clamped and gasketed in a 12 bolt flange on a large tubulation in the wall of the scattering section

Separate gas supply systems are provided for the arc section and scattering chamber to permit scattering experiments for systems of unlike molecules When possible, the gases are stored in small, high pressure steel cylinders, connected, through reducing valves, to the shut off valves, 16, which segregate the gas in the 500 cc. ballast tanks, 17, from the main supply, and are useful in preventing the pressure in the ballast tanks from building up in the event of a leak across the reducing valves of the storage cylinders The flow of gas is regulated by the needle valves, 19, which have 500 1 tapers and provide accurate control of the pressure in the arc section and scattering chamber. The throttled gas streams enter the apparatus through a second pair of shut-off valves, 20. Pump-out valves, 18, are provided for evacuating the ballast tanks before filling them to a pressure slightly above atmospheric. A by-pass valve, 21, permits the scattering chamber to be quickly evacuated to obtain unscattered beam intensities for comparison with scattered beam intensities All valves are packless, either diaphragm or bellows type, are made from brass forgings or machined from brass stock, and are individually tested for vacuum tightness

Except for the diffusion pump protection device and a motor-generator set which supplies 100 volts and 200 volts D C for the anode and cathode, all electrical controls and power supplies are housed in a standard, mobile relay rack. Switches for the arc section are high voltage relays, operated from 6 volt transformers, which reduce

[14] I Amdur, Rev Sci Inst *18*, 66 (1947)

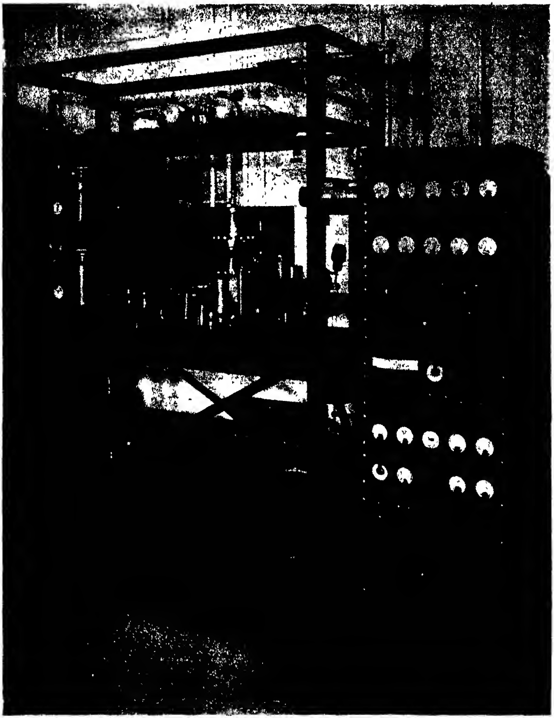

FIGURE 3 Apparatus and controls

danger of shock as well as arcing difficulties encountered when slow moving, conventional switches are used in high voltage, high current circuits. The use of separate 100 and 200 volt D. C. generators (instead of the laboratory D. C. mains) permits the anode and cathode to remain at their same potentials relative to the filament when the atom gun is grounded and the filament raised to variable positive potential in the measurement of positive ion scattering. The beam apparatus has been mounted on a steel angle iron frame which rests on large bakelite supports and is electrically isolated, since water leads to and from the arc section and diffusion pump are interrupted with 12 inch sections of glass tubing. It is therefore possible to place the entire apparatus at positive or negative potential for special purposes such as a study of the effectiveness of the top surface of the scattering chamber as an ion mirror Figure 3 is a photograph of the beam apparatus and its electrical controls. The diffusion pump is concealed by the panel of ballast tanks and valves for the gas supply systems, and a special galvanometer amplification arrangement[15] for measuring the detector response does not appear since it is in a section of the laboratory removed, as far as possible, from the electrical fields of the generators and power supplies.

2. *Performance Characteristics of the Apparatus*

a. *Detector Characteristics*

Two types of beam detectors have been built which operate by converting the kinetic energy of the high velocity beam particles into heat One type is a single junction radiation vacuum thermocouple[16] and the other, a compensated vacuum bolometer[17] Three vacuum thermocouples of different construction have been investigated. One, A, contains a circular receiver 0.279 cm. in diameter supported by one Chromel P and two constantan wires and masked with a circular opening 0 163 cm. in diameter; the second, B, contains a circular receiver 0 102 cm. in diameter supported by one Chromel P and one constantan wire and masked with a circular opening 0.051 cm. in diameter; and the third, C, which contains no receiver, was made by using a condenser discharge to butt weld a 0 0015 cm. diameter Chromel P wire, 0 318 cm long, to a 0 0013 cm diameter constantan wire, 0.318 cm. long, and is masked symmetrically about the weld with a rectangular opening, 0 051 cm. wide and 0 635 cm. long, whose long axis is perpendicular to the thermocouple The welded detector has been used for most of the preliminary measurements with the present apparatus and is shown in Figure 2A in the axis of the beam path The wires in thermocouples B and C are soldered to copper hemi-cylinders, separated by a mica spacer 0.001″ thick and pressed into a brass container which is insulated from the copper inserts by additional 0.001″ mica spacers. The bolometer, D, has a detecting element consisting of a blackened platinum wire 5.6×10^{-4} cm in diameter and 0 476 cm long which, like the welded thermocouple, acts as its own receiver The detectors were tested by irradiation in vacuum with light from a standard lamp in accordance with previously described procedures[16,17] The chief purpose in building the four detectors was to provide a method of varying the angular aperture of the detecting system since it has been shown[18] that experimentally determined cross-sections are functions of this aperture

The results of room temperature tests on the four detectors are summarized in Table I The angular apertures are the half angles subtended by the detector with respect to a point on the beam axis in the center of the gas confining region of the scattering chamber, namely, 0 253 cm. below the top surface of the upper section. These apertures differ by less than one per cent from values computed by averaging linearly over the 0 506 cm. distance which the beam travels in passing through the upper and lower sections of the scattering chamber. The radiant energy absorbed per second by each detector is given by $7.22 \times 10^{-5} \times 0\ 67 \times$ exposed area since the tabulated responses have been reduced to a common energy density falling per second on each detector, namely, 7.22×10^{-5} watts/cm² The detectors also have a common absorptivity, 0 67, which is characteristic of their aquadag coatings

[15] I. Amdur and H. Pearlman, Rev. Sci Inst. *9*, 194 (1938).

[16] I. Amdur and H Pearlman, Rev. Sci. Inst. *10*, 174 (1939).

[17] I. Amdur and C F. Glick, Rev. Sci. Inst *16*, 117 (1945).

[18] H. S. W. Massey and C B O. Mohr, Proc Roy Soc. *A141*, 434 (1933) H S. W. Massey and C. B. O Mohr, reference 4 R G. J. Fraser and L. F. Broadway, Proc. Roy Soc. *A141*, 626 (1933) L F Broadway, Proc. Roy. Soc *A141*, 634 (1933). W H Mais, Phys. Rev. *45*, 773 (1934) S. Rosin and I I Rabi, Phys. Rev. *48*, 373 (1935).

TABLE I

CHARACTERISTICS OF BEAM DETECTORS

Detector	Angular Aperture	Exposed Area (cm^2)	Power Absorbed (watts)	Response (volts)	Sensitivity (volts/watt)
A	2 35 degrees	$2\ 09 \times 10^{-3}$	$1\ 01 \times 10^{-6}$	$1\ 73 \times 10^{-6}$	1.71
B	44 0 minutes	$2\ 04 \times 10^{-3}$	$9\ 85 \times 10^{-8}$	$6\ 37 \times 10^{-7}$	6 47
C	1 21 minutes	$7\ 14 \times 10^{-5}$	$3\ 45 \times 10^{-9}$	$1\ 56 \times 10^{-7}$	45 2
D	28 9 seconds	$2\ 67 \times 10^{-4}$	$1\ 29 \times 10^{-8}$	$1\ 28 \times 10^{-6}$	99 2

For each detector, the room temperature sensitivity is constant with respect to radiation density flux in the range 0 to $7\ 22 \times 10^{-5}$ watts/cm.[2] by actual test.

In the case of a bolometer, the response is a function of the heating current. The value given for detector D in Table I is the maximum response and was obtained with a heating current of 0 92 milliamperes which produced a temperature rise of 55°.

b *Arc Characteristics*

Since, to date, helium has always been used both in the arc section and in the scattering section, the performance characteristics of the apparatus refer to that gas. For other gases, the characteristics would differ in specific detail but not in general character.

After inserting a new filament, the large by-pass valve, 13, is opened and both sections of the apparatus are evacuated to a pressure below 10^{-5} mm. The filament is then "broken in" by careful heating to decompose its carbonate mixture coating into an active oxide coating After the activation of a new filament, which requires about 15 minutes, the by-pass valve is closed and gas is admitted to the arc section at a pressure of about 0.4 mm. The anode and cathode are then shorted together and connected to the 100 volt D. C. source so that an arc is struck between the filament and the shorted electrodes. The shorting procedure has been found helpful in starting the arc, presumably because it provides a very much greater anode surface and eliminates the negative field which tends to return electrons to the filament. The arc is run in this manner until conditions become stable, after which the cathode is unshorted from the anode and operated at its proper negative potential It is extremely important to prevent the anode voltage from rising much above 40 volts, otherwise bombardment of the filament by large currents of high energy positive ions will strip the oxide coating and deactivate the filament. The tendency toward high anode voltages is very pronounced when a new filament is first used, due, possibly, to gaseous impurities liberated from the metal surfaces upon bombardment by ions. The situation is remedied by evacuating the arc section through the large valve to eliminate the impure gas mixture. After several cycles in which the arc is restarted following the removal of impure gas, the anode voltage assumes a value of 40 volts or less and the arc continues to start and operate satisfactorily as long as air, or other harmful foreign gas such as water vapor, is not admitted to the arc chamber. This is accomplished by keeping the entire apparatus under high vacuum when the arc is not operating It is because of the necessity for keeping the vacuum pumps in constant operation, that the protection device for the diffusion pump has been included in the apparatus. About 10 hours of arc operation are required to stabilize the arc and metal surfaces after insertion of a new filament, after which about an hour is required each time the arc is restarted after a shut down period exceeding several hours After the 10 hour conditioning period, it is possible to decrease the gas pressure in the arc section to about 0 2 mm. to obtain larger detector responses without loss of arc stability There is some evidence that the insertion of a copper liner inside the cathode results in lower anode voltages due, possibly, to the relative ease, compared to aluminum, with which copper sputters. The sputtering of the copper tends to produce a clean cathode surface, but since some of the sputtered metal deposits on the cooler turns of the filament and covers active oxide, much of the advantage with respect to increased filament life is probably lost. With proper precautions such as those described, filament life in excess of 100 hours can be obtained

The following record of the first 19 running hours of an arc using a copper lined cathode and a filament which lasted for 98 running hours, illustrates average satisfactory arc behavior during the early life of a filament

Typical atom gun-detector characteristics (obtained with the detector in the beam axis and the scattering chamber evacuated) for a properly functioning apparatus are shown in Figure 4 and correspond to the following arc conditions:

TABLE II

ARC CHARACTERISTICS FOLLOWING INSERTION OF A NEW FILAMENT

Time Hr.	Min.	Pressure Mm	Filament Amp	Filament Volts	Anode Amp	Anode Volts	Cathode Amp.	Cathode Volts	Remarks
	0	5×10^{-4}	3 0	0 7	—	—	—	—	Activation of filament Large by-pass valve open
	2	1×10^{-4}	4 0	1 4	—	—	—	-	
	4	1×10^{-4}	5 0	2 2	—	—	—	—	
	7	5×10^{-4}	6 0	3 1	—	—	—	—	
	9	1×10^{-4}	7 0	3 75	—	—	—	—	
	14	1×10^{-4}	8 0	4 4	—	—	—	—	
	15	1×10^{-4}	7 0	3 75	—	—	—	—	
	18	0 42	7 0	3 7	1 0	21	Sh to anode		Large by-pass valve shut Gas in arc section
	20	0 43	7 0	3 7	1 0	25	Sh to anode		Arc turned off Arc section pumped out
	25	0 27	7 0	3 7	1 0	21	Sh to anode		Arc restarted
	39	0 43	7 1	3 7	0 85	52	0 08	140	Cathode unshorted
	42	0 30	7 0	3 7	1 0	42	0 08	142	Arc turned off Arc section pumped out
1	2	4×10^{-3}	7 0	3 7	—	—	—	—	
2	4	2×10^{-3}	7 0	3 7	—	—	—	—	Difficulty in outgassing
2	35	0 31	8 0	4 3	0 45	40	0 08	140	Arc restarted
3	50	0 40	8 0	4 3	0 50	33	0 08	144	
6	35	0 45	7 7	4 1	0 80	44	0 11	140	Arc turned off
	0	0 42	7 5	3 9	1 0	24	Sh to anode		Arc started next day
	20	0 35	7 5	3 9	0 85	36	0 13	120	Cathode unshorted
4	5	0 31	7 5	4 0	0 90	29	0 14	120	
5	45	0 41	7 0	3 7	0 87	30	0 22	120	
8	5	0 31	7 0	3 7	0 79	37	0 22	124	Arc turned off Atom gun draws 2 ma at 800 volts
	0	0 42	7 5	4 2	0 90	38	0 22	120	Arc started next day
2	3	0 41	7 5	4 2	1 0	29	0 25	118	Atom gun draws 2 1 ma at 800 volts
4	33	0 36	7 0	3 8	0 80	38	0 28	120	Atom gun draws 2 4 ma at 800 volts

pressure—0 25 mm , filament—7 5 amp , 4.65 volts, anode—1.38 amp., 32 volts, cathode—0 30 amp , 170 volts For a given arc pressure, curves of the same shape are obtained for different steady arc conditions.

The curves in Figure 4 can be fitted with the following relations

$$I = 0\,40 + 2\,00 \times 10^{-3}V \text{ milliamperes} \qquad \text{(A) (3)}$$

$$E/I = 1\,48 \times 10^{-2}\, e^{2\,85 \times 10^{-3}V} \text{ microvolts/milliampere} \qquad \text{(B) (4)}$$

$$E = (5.92 \times 10^{-3} + 2\,96 \times 10^{-5}V)\, e^{2\,85 \times 10^{-3}V} \text{ microvolts} \qquad \text{(C) (5)}$$

where I, is the atom gun current, E, the electromotive force of the detector, and V, the atom gun voltage For the particular geometry of the present apparatus, these results indicate that at low voltages the efficiency of neutralization (defined as the *fraction* of energy striking the atom gun which appears in the form of high speed neutrals) decreases with increasing voltage while at higher voltages the efficiency increases, due, possibly, to improved focusing by the screen grid. This conclusion is obtained in the following way.

The fraction, F, of atom gun energy which is converted into neutral beam energy is $aE/(IV)$ where a is a voltage independent constant characteristic of apparatus geometry This fraction is given by

$$F = aE/(IV) = be^{2.85 \times 10^{-3}V}/V \qquad (6)$$

where $b = 1.48 \times 10^{-2}a$, and the rate of change of the fraction by

$$dF/dV = F(2.85 \times 10^{-3} - 1/V) \qquad (7)$$

This rate of change is negative below 350 volts and positive above, suggesting the previously mentioned change in efficiency of neutralization with increasing voltage.

For a different set of arc conditions, namely. pressure—0.24 mm.; filament—7.5 amp., 4.5 volts; anode—0 81 amp , 40.5 volts; cathode—0.24 amp., 172 volts, the same general results were obtained, as shown by the following relations:

$$I = 0\,32 + 1\,93 \times 10^{-3}V \text{ milliamperes} \qquad (8)$$

$$E/I = 1\,57 \times 10^{-2}\, e^{2\,83 \times 10^{-3}V} \text{ microvolts/milliampere} \qquad (9)$$

$$E = (5.03 \times 10^{-3} + 3.03 \times 10^{-5}V)\, e^{2\,83 \times 10^{-3}V} \text{ microvolts.} \qquad (10)$$

It is possible to obtain stable arc conditions and reproducible atom gun-detector characteristics for arc section pressures ranging from about 0.08

to 0.50 mm. The neutral beam intensity, however, is a fairly strong function of this pressure. For example, for an unscattered beam at 800 volts, an arc section pressure of 0.21 mm. produces a maximum detector response which decreases by 40 per cent at 0.42 mm. and by 20

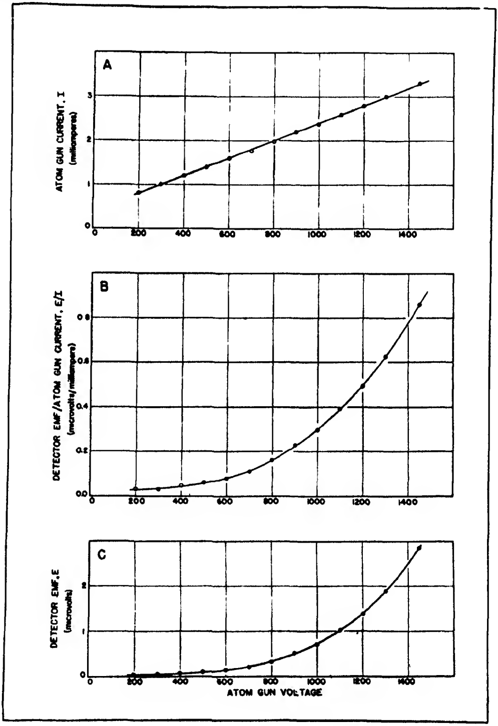

FIGURE 4. Typical atom gun-detector characteristics.

per cent at 0 09 mm. The decrease at higher pressures is probably due to scattering of high velocity ions on their way to the atom gun, and the decrease at low pressures, to the smaller number of positive ions which pass through the screen in preference to being neutralized at the cathode walls, as suggested by enhanced cathode currents at low pressures Whenever possible, therefore, an arc section pressure of about 0.2 mm. is used to obtain maximum detector responses for any given set of arc conditions

c. *Pirani Gage Characteristics*

The self-contained Pirani gage which measures the pressure of gas in the scattering chamber has been described in detail elsewhere.[19] It consists of a platinum wire, 1.37×10^{-3} cm in diameter and 4.57 cm. long, suspended between the upper and lower sections of the chamber A platinum wire compensator, in thermal contact with the walls of the scattering chamber, and two fixed manganin resistors are combined with the gage wire to form a Wheatstone bridge network which is in balance when the gage wire is about 2 degrees hotter than the compensator. For a given compensator temperature and a given gas, the scattering pressure is a single valued function of the bridge current at balance. Over a limited pressure range, it is possible to use an empirical relation which, for the present type of gage network, has the simple form

$$P = aI_B^{\gamma} - b \tag{11}$$

where P is the pressure and I_B, the bridge current at balance The constants a and b are characteristic of each gas and depend only upon the temperature. This temperature dependence may be deduced in the following manner.

When current, I, flows through the Pirani gage wire of resistance R, the energy balance may be written in the form

$$I^2R = A + B + C + D \tag{12}$$

where

A = radiation loss
B = wire conduction loss at zero pressure
C = additional wire conduction loss at pressure P
D = gas conduction loss at pressure P.

The heat flow problem formulated in Equation (12) has been previously analyzed in discussing the characteristics of a compensated bolometer,[17] and the results obtained indicate that, for the present gage, C may be treated as a constant small fraction (about 0.1) of D for pressures up to about 0.1 mm., the probable upper limit of scattering pressure which will be used in the apparatus Equation (12) may therefore be written

$$I^2R = I_0^2R + K\alpha P\overline{\Delta t}/\overline{T}^{\frac{1}{2}} \tag{13}$$

where I_0 is the current through the gage wire at zero pressure at bridge balance, α, the accommodation coefficient of the gas on the gage wire, $\overline{\Delta t}$, the average temperature excess of the gage wire with respect to the compensator at temperature t, $\overline{T}$, the average gas temperature (which may be set equal to $273 + t + \overline{\Delta t}/2$ or $274 + t$), and K, a constant for each gas which is independent of both temperature and pressure

The current which is read in the apparatus is not the gage wire current, I, but the total bridge current, I_B, whose relation to I is expressed by

$$I = \frac{I_B}{2\,525\,[1 + 2\,12 \times 10^{-3}(t - 26)]} \tag{14}$$

The gage resistance, R, and the average temperature excess, $\overline{\Delta t}$, are temperature functions given by

$$R = 36.483\,[1 + 3\,60 \times 10^{-3}(t - 26)]\text{ ohms} \tag{15}$$

and

$$\overline{\Delta t} = 2.114\,[1 + 3\,63 \times 10^{-3}(t - 26)]\text{ degrees.} \tag{16}$$

Since 26° C was the reference temperature at which the bridge characteristics were determined, the corresponding reference value for $\overline{T}$ must be taken as 300° K, whereupon Equation (13) reduces to

$$I_B^2 = I_{B(0)}^2 + K'\alpha P\,[1 + 2.60 \times 10^{-3}(t - 26)] \tag{17}$$

where $K' = K/46.88$ and where $I_{B(0)}$ by actual measurement is found to conform to the relation

$$I_{B(0)} = 1.977\,[1 + 3.69 \times 10^{-3}(t - 26)]\text{ milliamperes} \tag{18}$$

Equations (17) and (18) lead to the following equation for converting a bridge current, I_B, measured at temperature t and pressure P, to a corrected current, I_B^*, referred to 26° C and the same pressure.

$$I_B^{*2} = \frac{I_B^2}{1 + 2.60 \times 10^{-3}(t - 26)} - 18.7 \times 10^{-3}(t - 26) \tag{19}$$

Equation (17) does not transform directly into Equation (11) because the accommodation coeffi-

[19] I. Amdur, M. M. Jones and H. Pearlman, J. Chem. Phys. *12*, 159 (1944).

cient, α, is pressure dependent in the range of present interest, $0 - 0.1$ mm.[20] Yet, calibration results for ten gases, when corrected by Equation (19) to 26° C., gave very satisfactory straight line plots of P vs I_B^{*2} in the pressure range $0.008 - 0.12$ mm., showing that the form of Equation (11) is valid. The ratios of b/a did not equal $I_{B(0)}^{*2}$, (1.977 ma.),[2] however, and the straight line relation must therefore be considered empirical. That it is obtained at all is probably due to the fact that no attempt was made to force the constants a and b or the ratio b/a to adhere to theoretical or predetermined values and that the moderate pressure dependence of α was therefore absorbed in the mutual departure of a and b from such values.

The calibration results for the ten gases are summarized in Table III in terms of the values of the constants a and b in Equation (11) which define the best straight lines through the experimental points corrected to 26° C. Fifty experimental values were available in the desired pressure range, of which two, one each for helium and xenon, were discarded as being excessively in error. The second column lists the number of experimental values which were used in determining the constants for each gas, while the last two columns record absolute deviations of calculated pressures from experimental values.

TABLE III

PIRANI GAGE CALIBRATION AT 26° C. FOR $0.12 \text{ mm} > P > 0.008 \text{ mm}$

Gas	No of points	a mm -(ma)^2	b mm	Av Dev %	Max. Dev %
Helium	6	0.01093	0.04500	1.4	3.5
Neon	5	0.01362	0.05466	1.0	1.9
Argon	4	0.01567	0.06323	1.8	2.5
Krypton	5	0.02245	0.09160	0.9	1.4
Xenon	5	0.02776	0.1160	1.4	2.7
Hydrogen	5	0.006600	0.02700	1.6	2.5
Deuterium	5	0.007335	0.03054	0.8	1.3
Nitrogen	5	0.009813	0.04023	1.4	2.3
Carbon monoxide	4	0.009771	0.04070	0.2	0.4
Oxygen	4	0.01006	0.04027	0.8	1.2

At any temperature two readings of the bridge current are required to determine the scattering pressure. One reading, $I_{B(0)}$, at zero pressure serves to define t through Equation (18), so that the other reading, I_B, at pressure P, may be corrected to I_B^* at 26° C through Equation (19). The values of a and b appropriate to the gas are then selected from Table III and combined with I_B^* to calculate P from Equation (11).

[20] I. Amdur, J. Chem Phys *14*, 339 (1946)

d *Scattering Section Pressure Characteristics*

Whenever possible, the intensity of a beam which has been attenuated by passing through a layer of scattering gas is referred to the intensity of the unscattered beam to eliminate the difficult and unnecessary task of measuring absolute intensities. When it is not feasible to obtain an intensity measurement at essentially zero scattering pressure, the ratio of intensities at two known pressures serves equally well. This is illustrated by the following expressions for estimating the scattering mean free path at unit pressure and 273° K, L_v, of a beam particle which has traversed a uniform scattering region of length x.

Case 1—Scattered intensity, I, at pressure P and temperature T, reference intensity, I_0, at zero pressure

$$I/I_0 = \exp\left[-(273x/L_v)(P/T)\right] \qquad (20)$$

Case 2—Scattered intensity, I_1, at pressure P_1 and temperature T_1, reference intensity, I_2, at pressure P_2 and temperature T_2

$$I_1/I_2 = \exp\left[-(273x/L_v)(P_1/T_1 - P_2/T_2)\right] \qquad (21)$$

In the present apparatus the 0.020″ hole in the atom gun permits sufficient gas to flow from the arc section into the scattering section to cause significant scattering of the beam even when gas is not admitted into the scattering chamber, and the equivalent of Equation (21) must be used for mean free path calculations. The relation of the scattering section pressure to the arc section pressure under these conditions was determined for helium from readings of the thermocouple and ionization gages and found to conform to the type of relation required for free molecule flow. The actual relation may be written

$$P_{SS}^{\circ} = 6.11 \times 10^{-4} P_{AS} \quad (0.10 \text{ mm} < P_{AS} < 0.43 \text{ mm.}) \qquad (22)$$

where P_{SS}° is the scattering section pressure of helium due to pressure P_{AS} in the arc section when gas is not admitted to the scattering chamber. Similarly, by eliminating the flow of helium into the arc section and admitting gas to the scattering chamber, the increase in scattering section pressure, ΔP_{SS}, due to gas in the scattering chamber at pressure P_{SC} was determined from readings of the Pirani and ionization gages. The actual relation was found to be

$$\Delta P_{SS} = 1.41 \times 10^{-3} P_{SC} \quad (0.009 \text{ mm.} < P_{SC} < 0.10 \text{ mm.}) \qquad (23)$$

so that the total scattering section pressure of

helium when gas is present in both the arc section and scattering chamber is

$$P_{SS} = 6.11 \times 10^{-4} P_{AS} + 1.41 \times 10^{-3} P_{SC}. \quad (24)$$

As previously indicated, the reference intensity measurement (when gas is not admitted to the scattering chamber) is accompanied by weak scattering of the beam through the distance from the atom gun exit to the detector, 6.103 cm., due to pressure P_{SS}° as given by Equation (22). When gas is admitted to the scattering chamber, the scattering of the beam is no longer uniform due to the large difference in pressure existing inside the scattering chamber in comparison with that outside. Rosin and Rabi[18] have shown that this type of non-uniform scattering may be treated by resolving it into component parts which, in the present case, may be characterized as follows

1. Scattering from the atom gun exit to the scattering chamber entrance through 3.863 cm of gas at pressure P_{SS} as given by Equation (24)

2. Scattering in the cloud (cloud 1) formed by gas escaping from the entrance hole of the scattering chamber.

3. Scattering in the circular entrance channel (0.051 cm. diameter, 0.079 cm long) of the scattering chamber.

4. Scattering in the scattering chamber proper, a distance of 0.427 cm. from the rear of the entrance hole to the slit jaws. (The area of the slot above the jaws is sufficiently large and its length parallel to the beam axis sufficiently short, to render negligible pressure drops occurring in it when the slit jaws are in position.

5. Scattering in the exit slit which is actually a short, narrow rectangular channel. That the slit has significant length is due to the fact that the defining jaws do not have perfect knife edges. The cross sectional area of the channel is that of a rectangle, 1.00 cm. by 0.0025 cm., and its length is estimated to be 0.01 cm

6. Scattering in the cloud (cloud 2) formed by gas escaping from the exit slit of the scattering chamber.

7. Scattering from the scattering chamber exit slit to the detector through 1.734 cm. of gas at pressure P_{SS} as given by Equation (24).

The pressure distribution in the circular cross section entrance channel of the scattering chamber may be computed from formulas and tables given by Clausing[21] for the free molucule flow of gases through a variety of openings As gas flows outward from the scattering chamber through this channel toward the atom gun, the pressure drops linearly in the 0.079 cm length from $0.79P_{SC}$ on the inner side to $0.21P_{SC}$ on the outer side so that the average pressure in the channel is $0.50P_{SC}$ An exact method for calculating the pressure distribution in the cloud at the entrance channel of the scattering chamber does not seem to exist Fortunately, the scattering in the cloud is a small fraction of the total and very approximate estimates are sufficient The assumption of Rosin and Rabi, that the pressure in the cloud at its origin is half the pressure at the end of the channel, will be taken as the starting point In the present case, this leads to an origin value of $0.105P_{SC}$ Since most of the scattering of the beam will be confined to very small angles, the inverse square intensity law, which is a special case of the cosine law of molecular effusion, will be used to estimate pressures in the cloud at distances large in comparison with the channel radius This leads to

$$P_1(r) = 0.21P_{SC}(0.0255/r)^2 \quad (r >> 0.0255 \text{ cm.}) \quad (25)$$

where $P_1(r)$ is the pressure in cloud 1 at a distance of r cm. from its origin Equation (25) shows that the pressure in the cloud 0.310 cm from its source has already been reduced to a value indistinguishable from the increase in scattering section pressure due to gas in the scattering chamber, namely, $1.41 \times 10^{-3}P_{SC}$ The variation of pressure in cloud 1 over the entire 0.310 cm distance is adequately represented by the empirical relation

$$P_1(r) = 0.105P_{SC} \exp(-13.9r) \quad (26)$$

As gas flows outward from the scattering chamber through the rectangular cross section exit slit toward the detector, the pressure drops linearly in the 0.01 cm length from $0.80P_{SC}$ on the inner side to $0.20P_{SC}$ on the outer side, so that the average pressure in the short channel is $0.50P_{SC}$. In analogy with the procedure used for cloud 1, the pressure at the origin of the cloud emanating from the exit slit, cloud 2, will be taken as $0.10P_{SC}$ and the pressure at distances large compared with the longest beam dimension (about 0.05 cm.) will be computed from

$$P_2(r) = 0.20P_{SC}\,[0.0025/(\pi r^2)]. \quad (27)$$

Equation (27) predicts that the pressure in cloud 2 will reach the background value of 1.41×10^{-3} P_{SC} at $r = 0.336$ cm. The empirical relation

[21] P Clausing, Physica 9, 65 (1929)

which adequately represents the pressure distribution in the cloud over the entire 0.336 cm. distance is

$$P_2(r) = 0.100 P_{SC} \exp(-12.7r). \quad (28)$$

Equation (21) may now be converted into a form applicable to the present scattering situation by rewriting it as

$$I_1/I_2 = \exp[-(273/L_v)(\Sigma x_i P_i/T_1 - 3.73 \times 10^{-3} P_{AS}/T_2)] \quad (29)$$

where L_v must be expressed in cm and where $\Sigma x_i P_i$ is the sum of the effective values of xP_i for the seven component parts which constitute the total scattered beam when gas is admitted to the scattering chamber. In detail

$$\Sigma x_i P_i = 3.863 P_{SS} + \int_0^{0.310} P_1(r)dr + 0.079 \times 0.50 P_{SC} + 0.427 P_{SC} + 0.01 \times 0.50 P_{SC} + \int_0^{0.336} P_2(r)dr + 1.734 P_{SS} \quad (30)$$

which, upon evaluating the integrals and eliminating P_{SS} through Equation (24), simplifies to

$$\Sigma x_i P_i = 3.42 \times 10^{-3} P_{AS} + 0.495 P_{SC}. \quad (31)$$

The term $0.495P_{SC}$ in Equation (31) represents the total scattering contribution of the gas which is admitted to the scattering chamber. The scattering in both clouds contributed but 3 per cent to this total.

Equations (29) and (31) may be combined to give an equation from which L_v may be calculated from experimentally observable quantities, namely,

$$I_1/I_2 = \exp[-(273/L_v)(3.42 \times 10^{-3} P_{AS}/T_1 + 0.495 P_{SC}/T_1 - 3.73 \times 10^{-3} P_{AS}/T_2)] \quad (32)$$

In practice, $3.73 \times 10^{-3} P_{AS}$ is not likely to exceed 0.0015 (corresponding to a probable maximum arc pressure of 0.4 mm) and $0.495P_{SC}$ is not likely to fall below 0.004 (corresponding to a probable minimum scattering chamber pressure of 0.008 mm). Since T_1 and T_2 will seldom differ by more than one or two degrees, the ratio of $| 3.42 \times 10^{-3} P_{AS}/T_1 - 3.73 \times 10^{-3} P_{AS}/T_2 |$ to $0.495 P_{SC}/T_2$ will be about 1 : 32 in the most unfavorable case and $(3.42 \times 10^{-3} P_{AS}/T_1 - 3.73 \times 10^{-3} P_{AS}/T_2)$ may be replaced by $-3.1 \times 10^{-4} P_{AS}/T_1$ with insignificant loss in accuracy so that Equation (32) may be simplified to

$$I_1/I_2 = \exp[-135(P_{SC} - 6.3 \times 10^{-4} P_{AS})/(L_v T_1)]. \quad (33)$$

It must be remembered that Equation (33) applies only if the following conditions are satisfied.

1. Measurement of the reference intensity, I_2, must be made with no gas admitted to the scattering chamber.
2. T_1 must be approximately equal to T_2.
3. P_{SC} must not be appreciably less than 0.008 mm.
4. P_{AS} must not be appreciably greater than 0.4 mm. Conditions 2, 3, and 4 will usually be automatically fulfilled because of present apparatus characteristics. In the event that condition 1 is not fulfilled, it is possible to modify Equation (33) to correspond to specific operating conditions. For example, if an experiment were conducted under the following conditions.

1. Scattered intensity, I_1, at scattering chamber pressure P_{1SC} and temperature T_1,
2. Reference intensity, I_2, at scattering chamber pressure P_{2SC} and temperature T_2,
3. T_1 approximately equal to T_2,
4. Arc section pressure, P_{AS}, unchanged during measurement of I_1 and I_2,

the appropriate equation for estimating L_v would be

$$I_1/I_2 = \exp[-(135/L_v)(P_{1SC}/T_1 - P_{2SC}/T_2)]. \quad (34)$$

Although the pressures in Equations (33) and (34) may be expressed in any convenient units, it is customary to use millimeters of mercury, in which case L_v is the mean free path in cm. at 1 mm pressure and 273° K. For the present type of scattering system, the cross section, S_v, corresponding to L_v is given by

$$S_v = 1/(nL_v) \quad (35)$$

where n is the number of scattering particles, 3.54×10^{16}, per cc. at 1 mm. and 273° K if L_v is in cm. at 1 mm. and 273° K. Equations (33) and (34) may therefore be converted to

$$I_1/I_2 = \exp[-4.78 \times 10^{18}(P_{SC} - 6.3 \times 10^{-4} P_{AS}) S_v/T_1] \quad (36)$$

and

$$I_1/I_2 = \exp[-4.78 \times 10^{15} S_v (P_{1SC}/T_1 - P_{2SC}/T_2)] \quad (37)$$

respectively, for calculating S_v in cm.² from pressures expressed in mm.

e *Preliminary Scattering Results*

Preliminary scattering measurements for helium in helium have been made for atom gun

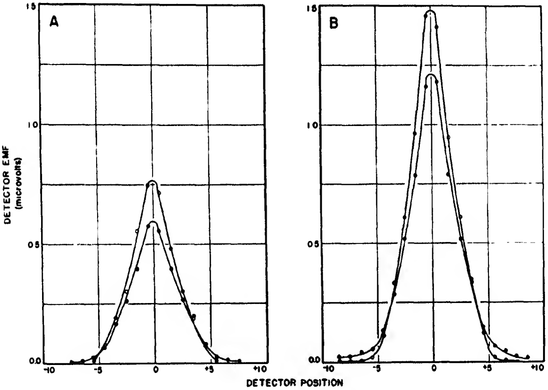

FIGURE 5 Scattering of helium in helium (Reference beam—o, scattered beam—●) A, 1000 volt beam, B, 1200 volt beam

voltages in the range 600–1200 volts In every case the scattered and reference beams were probed in the transverse direction in steps of 0.001″ to obtain profiles showing the angular intensity distribution All reference intensity measurements were made with no gas admitted to the scattering chamber Typical results for 1000 and 1200 volts (atom gun currents, 3.24 ma. and 3.65 ma., respectively) are shown in Figure 5 where the abscissa is the transverse position of the detector (in thousandths of an inch) relative to the point of maximum intensity. The arc characteristics were the same for both sets of measurements, namely: pressure—0 27 mm ; filament—7.3 amp , 4.40 volts, anode—0.82 amp., 41 volts; cathode—0.24 amp., 160 volts. Similarly, the pressure, P_{SC}, and temperature, T_1, of the helium in the scattering chamber were the same in both sets, 0.0165 mm , and 281 7° K The temperature, T_2, of the very low pressure gas in the scattering section during measurement of reference intensities was also 281 7° K.

If a true point detector were used to probe the intensity of the beam, because of the circular cross section of the scattering chamber entrance channel, the transverse and longitudinal profiles of the beam would be the same within the average angular limit, about 7 degrees, determined by the geometry of the exit slit. However, the detector used to obtain the results in Figure 5 has an effective exposed area of a rectangle 0.0014 cm. wide and 0.051 cm. long. Since the long dimension is parallel to the length of the exit slit, transverse motion is essential to obtain

measurements under aperture conditions (1.21 minutes) determined by the 0.0014 cm. dimension.

The curves of Figure 5 show that the resolution of the detector is sufficiently high to obtain a precise pattern of the angular distribution of beam intensity in the very narrow range of angle to which most of the scattering is confined. For example, at both 1000 and 1200 volts, about 90 per cent of the total reference beam intensity is confined to ± 0.0035″ of detector travel with respect to the maximum, corresponding to a symmetrical angular spread of 15.4 minutes about the beam axis. After scattering through 0.0165 mm. of helium, about 75 per cent of the total reference beam intensity is retained in this same region at both voltages.

By using ratios of peak intensities, it is possible to calculate L_v and S_v at 1000 and 1200 volts from Equations (33) and (36) and the values obtained are characteristic of the aperture determined by the width of the detector. If, instead of peak intensities, areas under the curves are used, mean free paths and cross sections are obtained which are characteristic of larger apertures determined by the abscissas which bound the areas. Thus, the use of a single movable detector of sufficiently small aperture can be used to obtain total collision scattering information characteristic, either of its own aperture, or of a series of detectors of larger aperture. This procedure is illustrated by the results in Table IV which compares values of L_v and S_v calculated from peak intensities with those calculated from areas corresponding to ± 0.0035″ of detector travel.

TABLE IV

EFFECT OF APERTURE ON L_v AND S_v

	Peak Intensities		Integrated Intensities	
Voltage	1000	1200	1000	1200
I_1/I_2	0.778	0.818	0.801	0.833
Aperture, min	1.21	1.21	15.4	15.4
L_v, cm (at 1 mm and 273° K.)	0.0312	0.0390	0.0353	0.0428
S_v, 10^{-16} cm^2	9.06	7.24	8.00	6.60

Although extended measurements on the scattering of high velocity neutral helium atoms are contemplated, the preliminary typical results of Table IV, coupled with previous collision cross section measurements of Amdur and Pearlman,[12] indicate that the present apparatus is capable of supplying quantum mechanical cross sections corresponding to the limit of zero aperture. For example, at 1000 volts, the previously determined value of S_v was 0.9×10^{-16} cm.^{2} at an average aperture of 2.25 degrees. When this aperture is reduced by about 9 fold, to 15.4 minutes, a correspondingly large increase (about 9 fold) in S_v results and a value of 8.00×10^{-16} cm.^{2} is obtained. Massey and Mohr[15] have shown, on theoretical grounds, that a large increase in total cross section should occur as the aperture is decreased from large values where the scattering is classical, to small values where diffraction arising from the de Broglie wave character of the scattering system produces extremely high intensity small angle scattering. They further show that the cross section should approach a finite limit as the aperture approaches zero, instead of increasing indefinitely as predicted by classical theory. The results of Table IV confirm the existence of this limit, since a further decrease in aperture of approximately 13 fold (from 15.4 min. to 1.21 min.) merely increases S_v by 13 per cent, from 8.00×10^{-16} cm.^{2} to 9.05×10^{-16} cm.^{2} In general, it is felt that the character of the curves in Figure 5 (high symmetry and overall small scattering of points) and the results of Table IV confirm the expectation that the present apparatus will be capable of supplying scattering results for high velocity beams of the same high quality as those obtained by Mais[16] and by Rosin and Rabi[18] for thermal velocity beams of alkali metals.

D. SUMMARY

An apparatus has been described for producing and scattering high velocity neutral particle beams with energies of 200 to 2000 electron volts. Special features of the apparatus include the use of detectors with small angular apertures, as low as 28.9 seconds of arc, isolation of the scattering gas in a small fraction of the distance between beam source and detector in order to define the angular aperture more sharply, and facilities for accurately probing the beam to obtain measurements of intensity as a function of angle. Extended tests of the apparatus have been made and performance characteristics of vital sections have been given to illustrate the quality of control of which the apparatus is capable and the range of variables which can be covered. Typical preliminary results for 1000 and 1200 volt helium atoms scattered in helium have been presented and analyzed. It is concluded that the present apparatus is capable of supplying scattering information of the same high quality as that available for thermal velocity beams.

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There were present fifty-nine Fellows and twenty guests

The records of the meeting of May 10 were read and approved

The Corresponding Secretary reported the receipt of letters accepting Fellowship from the following· Isadore Amdur, Adolf Augustus Berle, Jr , Douglass Vincent Brown, William Bell Dinsmoor, Henry Grattan Doyle, Maxwell Finland, Carl J Friedrich, Raymond Blaine Fosdick, Paul Rupert Gast, Walter Gropius, Arthur Robert von Hippel, Ernest Martin Hopkins, Columbus O'Donnell Iselin, James Rhyne Killian, Jr . Ronold Wyeth Percival King, Clyde Kay Maben Kluckhohn, Eugene Markley Landis, Ambrose Lansing, Elias Avery Lowe, Saunders MacLane, William Malumud, Richard von Mises, Charles Rufus Morey, John von Neumann, Linus Carl Pauling, Hugh Miller Raup, Albert Charles Smith, Harald Ulrik Sverdrup, Karl Terzaghi, George Widmer Thorn, La Rue Van Hook, Karl Vietor, Sarah Wambaugh, Edgar Bright Wilson, Jr., Charles Edward Wilson, Herbert Eustis Winlock, and from Amado Alonso, Ezequiel Ordoñez, and Daniel Cosío Villegas accepting Foreign Honorary Membership, also letters declining Fellowship from Vera Micheles Dean and Leverett Saltonstall

He also reported the receipt of a letter from Melvin T Copeland resigning Fellowship

The Corresponding Secretary reported that the Council had accepted the Report of the Committee of the Permanent Science Fund in which four grants in aid had been made

1. To Charles A. Berger, Professor of Cytology and Head of Biology Department, Fordham University, for assistance in continuing studies of the effect of nutrients upon Chromosomes, $500.

2. To T. T. Chen, Lecturer in Zoology, University of California, Los Angeles, for assistance in further studies on Cytogenetics of Protozoa, $250

3 To C. T Hurst, Director of Museum, Western State College of Colorado, for assistance and necessary travel in expanding his archaeological explorations in Colorado, $300

4 To J Schiller, Fearing Research Laboratory, Free Hospital for Women, Boston, for expendable materials and assistance in studies on steroid hormones, $500

After the introduction of new Fellows, the following communication was presented

Howard Mumford Jones. *The American Academy its Status and Prospects*

The following papers by P. W Bridgman were read by title *The Compression of 61 Solid Substances to 25,000 kg/cm², Determined by a New Rapid Method; The Compression of Twenty-one Halogen Compounds and Eleven Other Simple Substances to 100,000 kg/cm²*

The meeting was dissolved at 9 50 P M

One Thousand Two Hundred and Ninety-seventh Meeting

NOVEMBER 8, 1944—STATED MEETING

The Academy met at its House at 8·20 P M

The President in the Chair

There were sixty-two Fellows and thirty-one guests present

The records of the meeting of October 11 were read and approved

The Corresponding Secretary announced that the President had been authorized to appoint a commission of five Fellows to study the functions of the Academy

The Corresponding Secretary reported that Reid Hunt and Archibald T. Davison have been transferred to the status of Fellows Emeriti

Frederick H Pratt called attention to E. L Mark's sixtieth anniversary as a Fellow and stated that the Council had voted to send him a note of congratulation ·

After the introduction of new Fellows the following communications were presented

Edwin J. Cohn· *Blood Is a Very Special Juice*

Charles A. Janeway *The Use of Blood and Blood Derivatives in Medicine*

Franc D Ingraham *The Use of Blood Derivatives in Surgery.*

The meeting was dissolved at 10 25 P M

One Thousand Two Hundred and Ninety-eighth Meeting

DECEMBER 13, 1944 —STATED MEETING

The Academy met at its House at 8·25 P. M

The President in the Chair

This meeting had been designated as Ladies' Night, and there were present more than two hundred and fifty Fellows and guests

The records of the meeting of November 8 were read and approved

The following communication was presented

Francis Henry Taylor· *The Problem of Salvage and Restitution of the Artistic Treasures of Europe*

An exhibit, *Quartz Goes to War*, was on view in the office, Mr. Ernest R Bohro, of the August E Miller Laboratories, being the demonstrator

The meeting was dissolved at 9 40 P. M

One Thousand Two Hundred and Ninety-ninth Meeting

JANUARY 10, 1945 — STATED MEETING

The Academy met at its House at 8 20 P. M

The President in the Chair

There were present twenty-nine Fellows and fourteen guests

The records of the meeting of December 13 were read and approved

The Corresponding Secretary announced that the Council had appointed Harlow Shapley as Chairman of the Rumford Committee in place of the late Norton A Kent

The President announced that the Boston Institute for Religious and Social Studies will hold meetings at the house of the Academy on eight successive Tuesdays, beginning January 23

The following communication was presented

Karl Terzaghi *Soil Mechanics*

There was an exhibit of *Some Early New England Refractories used by Paul Revere in his Smelter at Norton, Mass*, arranged by Professor Frederick H Norton, of the Massachusetts Institute of Technology

The meeting was dissolved at 10 15 P M

One Thousand and Three Hundredth Meeting

FEBRUARY 14, 1945 —STATED MEETING

The Academy met at its House at 8 20 P M

The President in the Chair.

There were present twenty-three Fellows and eighteen guests

In the absence of the Recording Secretary his duties were performed by the Corresponding Secretary

The records of the meeting of January 10 were read and approved

The following communication was presented

William Malamud *A Psychiatric Approach to the Problem of Veteran Readjustment*

An exhibit of material concerning Massachusetts veterans in former wars was arranged through the courtesy of the Harvard College Library

The meeting was dissolved at 9·45 P. M

One Thousand Three Hundred and First Meeting

MARCH 14, 1945.—STATED MEETING

The Academy met at its House at 8 25 P M

Vice-President Robinson in the Chair

There were present forty-two Fellows and eighteen guests

The records of the meeting of February 14 were read and approved

It was announced that the President had appointed a Nominating Committee, as follows Bart J Bok, of Class I; Frederick K. Morris, of Class II, *Chairman*, Charles E Wyzanski, Jr., of Class III, Leonard Carmichael, of Class IV.

Announcement was also made of the appointment of a Committee to study the structure and operation of the Academy, in accordance with a vote of the Council last November. This Committee, which has already held two meetings, consists at present of four members Kirtley F Mather, *Chairman*, Curt J Ducasse, John W M Bunker, and Leonard Carmichael

On the recommendation of the Council the following appropriations were voted for the year 1945–1946

From the income of the General Fund, \$7,800, to be used as follows:

for House expenses	\$2,600
for General and meeting expenses	1,000
for Library expenses	3,000
for Treasurer's expenses	1,200
Total	\$7,800

From the income of the Publication Funds, \$2,400, to be used for publication

From the income of the Rumford Fund, $3,370, to be used at the discretion of the Committee.

From the income of the C. M. Warren Committee, $1,000, to be used at the discretion of the Committee

The following communication was presented

Douglas Bush. *The Humanities and Science in Education in the Seventeenth and Twentieth Centuries.*

There was an exhibit of famous Renaissance treatises, loaned by the Houghton Library of Harvard University.

The meeting was dissolved at 9 45 P. M

One Thousand Three Hundred and Second Meeting

APRIL 11, 1945 —STATED MEETING

The Academy met at its House at 8 27 P M

The President in the Chair.

There were present thirty-one Fellows and sixteen guests

In the absence of the Recording Secretary, his duties were performed by the Corresponding Secretary

The records of the meeting of March 14 were read and approved

It was announced that an amendment to the Statutes establishing the Committee on the Permanent Science Fund as a standing committee will be submitted to the Academy for action at its meeting on May 9

Announcement was made of the proposed Regulations for the Conference of Secretaries of the American Council of Learned Societies Approval of these regulations will be requested at the next Academy meeting.

The following communication was presented

Henry Allen Moe *The Selection of Persons for Research Fellowships*

The meeting was dissolved at 9.42 P. M.

One Thousand Three Hundred and Third Meeting

MAY 9, 1945.—ANNUAL MEETING

The Academy met at its House at 8 20 P. M.

The President in the Chair

There were present forty-four Fellows and nine guests.

The records of the meeting of April 11 were read and approved.

The following reports were presented

REPORT OF THE COUNCIL

Since the last report of the Council there have been reported the deaths of seventeen Fellows: George David Birkhoff, Alexis Carrel, George Whiteley Coggeshall, Alfred Victor de Forest, Edmund Burke Delabarre, Carl Engel, Frederic Harold Fay, James Ford, Philip Fox, Roy Kenneth Hack, William Henry Howell, Walter Louis Jennings, Norton Adams Kent, Charles Francis Park, Robert Hallowell Richards, Frederick Slocum, William Trelease, and nine Foreign Honorary Members: Rt Hon James Richard Atkin, Sir Thomas Barlow, Godfrey Rathbone Benson, Baron Charnwood, Gustav Cassel, Sir Arthur Stanley Eddington, Sir William Napier Shaw, Aurel Stodola, Peter B Struve. Three Fellows have resigned Melvin Thomas Copeland, William Leonard Crum, Alan Richards Moritz

Twelve names have been added to the list of Fellows Emeriti: Walter Bradford Cannon, Charles Townsend Copeland, Archibald Thompson Davison, Richmond Laurin Hawkins, Frank Lauren Hitchcock, Reid Hunt, Charles Palache, Walter Raymond Spalding, Clair Elsmere Turner, Alfred North Whitehead, Edmund Allen Whitman, Frederick Shenstone Woods

Thirty-nine Fellows and four Foreign Honorary Members were elected by the Council and announced to the Academy in May, 1944 All of these have accepted their election with two exceptions—Vera Micheles Dean and Leverett Saltonstall—who declined

The roll now includes 767 Fellows, 17 Fellows Emeriti, and 113 Foreign Honorary Members (not including those elected in May, 1945)

REPORT OF THE TREASURER

(*Extract*)

In the absence of the Treasurer, his report was read by the Corresponding Secretary A summary of the receipts and expenditures follows.

*RECEIPTS, 1944–1945

Academy, General			
From: Investment Income	$13,849 82		
Less. Income to Special Funds	10,972 73		
		$2,877 09	
Assessments and Admission Fees		4,250 00	
			$7,127 09
Amory Prize Committee			
From: Investment Income			3,352 27
Publications Committee.			
From: Investment Income		$2,303 04	
Sale of Publications		722 39	
Lake Publication, Subscriptions		182 80	
			3,208.23

*Excluding sales of securities

Rumford Committee		
From. Investment Income		3,255 41
C. M Warren Committee		
From Investment Income		988 35
Mabel S Agassiz Fund		
From: Investment Income		107 40
Permanent Science Fund		
From Boston Safe Deposit and		
Trust Co , Trustee	$10,820 19	
Investment Income	898 23	
		11,718 42
Kennelly Fund		
From Investment Income		68 03
Total Receipts		$29,825 20

*Expenditures, 1944–1945

Academy, General			
Library, Salaries	$2,432 00		
Books and Binding	764 79		
		$3,196.79	
General (Net)		1,062 87	
House (Net)		2,600 13	
Treasurer's Office		599 94	
Insurance		578 25	
			$8,037 98
Amory Prize Committee			
Expense			13 75
Publications Committee			
General		$604 81	
Lake		13 00	
			617 81
C M Warren Committee			
Grants		$540 00	
Transfer of Income to Fund		1,000 00	
			1,540 00
Mabel S. Agassiz Fund			
For Meetings			107 40
Permanent Science Fund			
Grants			2,280 00
Total Expenditures			$12,626 94

REPORT OF THE RUMFORD COMMITTEE

On behalf of the Rumford Fund Committee of the American Academy of Arts and Sciences, I report that during the past year there have been no applications for grants-in-aid received by the Committee

In view of the current security regulations which prevent our knowing fully of important contributions of the past few years in the fields of heat and light, the Rumford Fund Committee has decided not to recommend candidates for the Rumford Medals

The Treasurer reports the total funds available for the work of the Committee on March 12, 1945, is $10,113.84, and that the estimated income for 1945–1946 is $3,370

Respectfully submitted,
Harlow Shapley, *Chairman*

May 9, 1945

REPORT OF THE CYRUS M. WARREN COMMITTEE

The Committee had available for grants during the fiscal year 1944–1945 a total sum of $1,669.53, of which $870 00 was appropriated at the March, 1944 meeting and $799 53 remained as a balance from the previous year. It was considered advisable, and so voted by the Committee, to return $1,000 00 to the principal Grants were made totalling $390 00, as follows

To Doctor Ralph N. Prince of the University of New Hampshire, a grant of $200 00 for materials to construct apparatus in connection with a project to develop an optical means of determining the purity of cellulosic materials

To Professor Pierre Van Rysselberghe of the University of Oregon, a grant of $190 00 for the purchase of a Leeds and Northrup audio frequency oscillator for use in the dertermination of the conductances of non-aqueous solutions of metallic salts, particularly those of magnesium and aluminum

A further report was received from Professor Thomas W Davis of New York University in regard to his grant of the preceding year After considerable delay he was able to secure a suitable fractionating column for which the grant was awarded

Respectfully submitted,
Frederick G. Keyes, *Chairman*

May 9, 1945

REPORT OF THE COMMITTEE OF PUBLICATION

The Publication Committee has held no regular meetings this year, business having been transacted by consultation and correspondence Three numbers of the *Proceedings* have been published

Volume 75

5 Barnett, S J *New Researches on Magnetization by Rotation and the Gyromagnetic Ratios of Ferromagnetic Substances* pp 109–129 August, 1944

6 *Presidential Address, Records of Meetings, Biographical Notices, Presidents of the Academy, Officers and Committees, List of Fellows and Foreign Honorary Members, etc*, pp. 131–208. December, 1944

Volume 76

1 Bridgman, P W *The Compression of Twenty-one Halogen Compounds and Eleven Other Simple Substances to 100,000 kg/cm²; the Compression of Sixty-one Solid Substances to 25,000 kg/cm², Determined by a New Rapid Method.* pp. 1–24 February, 1945.

The Index to Professor and Mrs. Lake's *Dated Greek Minuscule Manuscripts to the year 1200* has been en-

*Excluding purchases of securities

tirely printed off and is being bound. It forms a monograph of smaller format than the plates—about 200 pages. It seemed wise to print a larger number of these as there will be individual sales for it in addition to those to subscribers to the series.

Professor Hatch's *Dated Syriac Manuscripts* is in corrected page proof, but has not, at last reports, been printed off. There are no other papers on the roster for publication.

Respectfully submitted,
ROBERT P. BLAKE, *Chairman*

May 9, 1945

REPORT OF THE LIBRARY COMMITTEE

During the year, 111 bound volumes (mainly of serials) were added to the library, making a total of 47,372 now on the shelves Of this number 97 were received by gift or exchange and 14, or only 8 per cent, were purchased The appropriation was $2,625 for the year ending March 31, 1945 Expenditures were as follows:

Salaries	$2,432 00
Purchase of books and periodicals	522 54
Binding and repairing	242 25
Total	$3,196 79

In addition to the use of books in the building, 57 books and pamphlets were borrowed by 5 Fellows and 19 libraries

Thus reads, in general, the gist of annual reports varying little within the present century, in the earlier years of which the Academy ceased adding to its book collection, concentrated upon its periodical files—and made almost negligible use of either Yet the library, a terra incognita to most of our Fellows, has been in a sense the integrating symbol of the Academy as generations have passed Our shelves still hold the books of eighteenth-century founders; and accessions of the nineteenth-century form a unique record of the scientific and humanistic interests of the Academy throughout that period Since then, the principal growth has been in periodical files, so that now the stacks groan with memoirs and transactions from every intellectual quarter of the globe.

A recent inspection of the shelves kindly undertaken by a group of expert librarians has emphasized the potential value of our unexploited resources At the same time the opinion was expressed that these resources can be made useful only in so far as they are selectively dispersed to areas which lack, rather than duplicate the material. Your Committee are not in sufficient agreement to render concerted opinion, but the facts should be understood by all.

To our great misfortune, the extent of appropriation and personnel allotted to the upkeep of the collection has for many years been insufficient to cope with a growth which now nears the 50,000-volume mark The library has had throughout not only to shoulder the highly detailed work of the general secretariat, but to carry it under the library appropriation This means that there can be no strictly full-time staff service, and no provision for the conservation of library property except through part-time janitorial effort It means above all an undue demand upon the Assistant Librarian, whose executive duties greatly limit the exercise of her technical library training and experience

The librarian of an earlier generation, in reporting the inability of one person to handle both library and general Academy business, took occasion to note the "crumbling away" of the old bindings Seven years later, in 1913, his successor estimated that, in the new building, overcrowding was provided against for fifteen years Now, after thirty years' growth, the congestion is deplorable and "crumbling" unabated, with no relief in sight other than drastic dismemberment applied to all but historic treasures, the salvage of which is already proving a long and expensive process

Hence from more than one direction we are impelled toward some form of radical action Nevertheless, to those who know our library it has a strong utilitarian as well as antiquarian appeal To these it continues to prove an invaluable resource, containing as it does many long and rare files and offering to Fellows certain privileges of withdrawal unapproached in their liberality Your Committee invite examination of the stacks and urge full consideration of the situation It is one of the major problems now before us

Respectfully submitted,
FREDERICK H PRATT, *Chairman*

May 9, 1945

REPORT OF THE HOUSE COMMITTEE

During the year ending March 31, 1945, the House Committee has had at its disposal funds amounting to $2,852 69, as follows

Appropriation for 1944–1945	$2,600 00
Received from other societies for the use of House facilities	252 69
Total	$2,852 69

The expenditures amounted to $2,852 92 Of this sum $2,699 83 was spent for the routine expenses, janitor, heat, light, telephone, etc, and $153 09 for the upkeep of the building

Meetings have been held as follows

The Academy	8
American Council of Learned Societies	3
Archaeological Institute of America, Boston Chapter	1
Boston Surgical Society	3
Institute for Religious and Social Studies	8
New England Botanical Club	9
Pan-American Society of Massachusetts	10
United China Relief	4
Total	46

The Council Chamber has been used for the Academy Council and Committee meetings, and also by the

Trustees of the Children's Museum and the New England Farm and Garden Association

A detailed list of the expenditures follows

Janitor	$1,001 00
Fuel	1,013 58
Electricity Light	197 73
Power	46 28
Elevator service and repairs	134.24
Telephone	155 96
Gas	54 90
Water	64 40
Upkeep of building	153 09
Janitor's supplies and sundries	31 74
Total	$2,852.92

The Academy received during the year by gift from Mrs Maximilian Agassiz portraits of Louis, Alexander, and Maximilian Agassiz, and a bronze bas-relief of Alexander Agassiz together with a copper plate inscribed with resolutions passed in his memory by the stockholders of the Calumet & Hecla Consolidated Copper Co These have been hung in the rooms of the Academy A letter of thanks was sent to Mrs Agassiz by the Chairman of the House Committee

Respectfully submitted,

C M Spofford, *Chairman*

May 9, 1945

The Corresponding Secretary announced that the following had been elected members of the Academy

FELLOWS

Class I, Section 1

Garrett Birkhoff — Cambridge
Norman Levinson — Belmont

Class I, Section 2

Robley Dunglison Evans — Belmont

Class I, Section 3

Eric Glendinning Ball — Newton Highlands
Arthur Clay Cope — Belmont
John Lawrence Oncley — Watertown

Class I, Section 4

Hardy Cross — New Haven, Conn
Frederick Emmons Terman — Belmont
John Benson Wilbur — Belmont

Class II, Section I

Martin Julian Buerger — Lincoln
Henry Crosby Stetson — Belmont

Class II, Section 2

Dennis Robert Hoagland — Berkeley, Calif
Herman Augustus Spoehr — Palo Alto, Calif

Class II, Section 3

John Robert Loofbourow — Cambridge
John Henry Welsh, Jr — Cambridge
Leland Clifton Wyman — Jamaica Plain

Class II, Section 4

James Morison Faulkner — Brookline
Thomas Hale Ham — Brookline

Class III, Section 3

Seymour Edwin Harris — West Acton
William Rupert Maclaurin — Cambridge
Talcott Parsons — Belmont
Howard Eugene Wilson — West Newton

Class III, Section 4

Edwin Sharp Burdell — New York, N Y
William Lockhart Clayton — Washington, D. C
Henry Allen Moe — New York, N Y

Class IV, Section 1

Edwin Ray Guthrie — Seattle, Wash
Charles Lincoln Taylor, Jr. — Cambridge

Class IV, Section 3

George Wiley Sherburn — Cambridge
Taylor Starck — Cambridge

Class IV, Section 4

Samuel Chamberlain — Marblehead
William Alexander Jackson — Cambridge
Keyes DeWitt Metcalf — Belmont
Martin Wagner — Cambridge

FOREIGN HONORARY MEMBERS

Class I, Section 1

Sir Harold Spencer Jones — Greenwich

Class I, Section 2

Niels David Bohr — Copenhagen

Class III, Section 3

Dennis Holme Robertson — London

Class III, Section 4

Alfredo L Palacios — Buenos Aires

Class IV, Section 3

Tomás Navarro Tomás — Madrid

It was voted to adopt an amendment to the Statutes by inserting in Chapter XI in Article 2 the following paragraph

The Permanent Science Fund Committee, to consist of seven Fellows, which shall recommend from time to time to the Council all appropriations from the income received by the Academy from the Trustee of the Permanent Science Fund, for effecting the purposes set forth in the Agreement and Declaration of Trust which governs the use of this Fund

It was voted to approve amendments to the constitution and by-laws of the American Council of Learned Societies, providing for a conference of secretaries at the annual meeting of the Council

On the recommendation of the Treasurer it was voted that the annual assessment for resident Fellows for the year 1945–1946 be fifteen dollars

The annual election resulted in the choice of the following officers and committees.

Howard M. Jones	*President*
George R. Harrison	*Vice-President for Class I*
Alfred C. Lane	*Vice-President for Class II*
Ralph E. Flanders	*Vice-President for Class III*
Fred N. Robinson	*Vice-President for Class IV*
Abbott P. Usher	*Corresponding Secretary*
Hudson Hoagland	*Recording Secretary*
Horace S. Ford	*Treasurer*
Frederick H Pratt	*Librarian*
Robert P Blake	*Editor*

COUNCILLORS FOR FOUR YEARS

John H. Van Vleck	Class I
Charles H. Blake	Class II
Oliver M. W Sprague	Class III
Harry A. Wolfson	Class IV

COMMITTEE ON POLICY AND RESOURCES

For Five Years W. Cameron Forbes

FINANCE COMMITTEE

Jerome C Hunsaker — Henry P Kendall
Ralph E. Freeman — John F Ebersole

RUMFORD COMMITTEE

Harlow Shapley, *Chairman*

Percey W. Bridgman — Robert B Lindsay
Harry M. Goodwin — Francis O Schmitt
George R Harrison — Edwin H Land

C M. WARREN COMMITTEE

Frederick G Keyes, *Chairman*

Gregory P. Baxter — Avery A Morton
Charles A Kraus — Walter C Schumb
Grinnell Jones — Kenneth L Mark

COMMITTEE OF PUBLICATION

Robert P Blake, *Chairman, ex officio*

Edwin C. Kemble	Class I
Ralph H Wetmore	Class II
Arthur H. Cole, .	Class III
Robert P Casey	Class IV

COMMITTEE ON THE LIBRARY

Frederick H. Pratt, *Chairman, ex officio*

Raymond C. Archibald	Class I
Thomas Barbour	Class II
Francis N. Balch	Class III
Henry B Washburn	Class IV

AUDITING COMMITTEE

Erwin H. Schell — Alexander Forbes

HOUSE COMMITTEE

Charles M. Spofford, *Chairman*

H. Addington Bruce — Robert P. Bigelow
Donald S. Tucker

COMMITTEE ON BIOGRAPHICAL NOTICES

For Three Years

Alfred C. Lane — Austin W. Scott

COMMITTEE ON MEETINGS

The President
The Recording Secretary

Leonard Carmichael — Jerome D Greene
Abbot P. Usher — Frederick K. Morris

The following communication was presented

Joseph P. Hudnut and Carl J Friedrich *The Boston Contest*

The meeting was dissolved at 10 20 P M

One Thousand Three Hundred and Fourth Meeting

OCTOBER 10, 1945 —STATED MEETING

The Academy met at the Old South Parish House Building, in Copley Square, at 8 15 P M., the change of meeting place having been made necessary by repairs to the house of the Academy

This meeting had been designated as Ladies' Night, and there were present about three hundred Fellows and guests

The reading of the records of the meeting of May 9 was omitted

The following communication was presented

Harlow Shapley. *Report on Soviet Science*

The meeting was then dissolved

One Thousand Three Hundred and Fifth Meeting

NOVEMBER 14, 1945.—STATED MEETING

The Academy met at the Old South Parish House Building at 8·22 P M

The President in the Chair.

There were present fifty-one Fellows and twenty guests.

The records of the meetings of May 9 and October 10 were read and approved

It was voted to discontinue the Committee on Policy and Resources (a standing committee), through an amendment to the Statutes, deleting Paragraph ii, Article 2, of Chapter XI

Professor Robley D. Evans was presented to the Academy by Vice-President George R. Harrison.

The Chairman of the House Committee reported on the progress of the plans for the alteration of the Academy's House.

The President announced that the four Vice-Presidents had been asked to prepare lists of the war work of the Fellows in their Classes, and gave a brief review of the partial returns reported by three of them.

The topic for the evening was *A National Policy for Scientific Research* and it was presented as a symposium by Messrs. Bradley Dewey, Pendleton Herring and Lee A Du Bridge The communications were followed by a lively discussion from the floor

The meeting was dissolved at 10 15 P M

One Thousand Three Hundred and Sixth Meeting

DECEMBER 12, 1945 —STATED MEETING

The Academy met at the Old South Parish House Building at 8 25 P M

The President in the Chair.

There were present thirty-seven Fellows and fourteen guests

In the absence of the Recording Secretary, the Corresponding Secretary read the records of the meeting of November 14, which were approved by the Academy.

The Corresponding Secretary reported that the Council had prepared a number of amendments to the Statutes designed to clarify the language of several paragraphs, to define more adequately the powers and duties of the President, and to describe the procedure on amendments that has in fact been followed since the establishment of the Council

The following communication was presented

Charles E Wyzanski, Jr *The War Criminal Trials*

After a stimulating discussion, the meeting was dissolved at 10 P. M

One Thousand Three Hundred and Seventh Meeting

JANUARY 9, 1946 —STATED MEETING

The Academy met at the Old South Parish House Building at 8·20 P. M

The President in the Chair

There were present eighty-four Fellows and thirty-four guests

The records of the meeting of December 12 were read and approved.

In the absence of the Corresponding Secretary, the Recording Secretary announced that the Council had adopted the following resolution·

Believing that the peace of the world and the advancement of the arts, the sciences, and education in all countries can be effectively furthered by an active support of the United Nations Educational, Scientific and Cultural Organization, the Council of the American Academy of Arts and Sciences congratulates the Senate and House of Representatives of the Congress of the United States upon the several resolutions adopted by them favoring support of this organization, and urges upon the Congress the desirability of ratifying the charter of the organization on the basis of the signature of our representatives at the London Conference last November

In order that the widest support may be given to the United Nations Educational, Scientific and Cultural Organization, the Council desires that copies of this resolution shall be sent to all the learned and scientific bodies throughout the world with which it has communication, to the public press, to the President of the United States, the Secretary of State, the Speaker of the House, the President of the Senate, and the Assistant Secretaries of State.

The President announced that instead of the usual stated meeting in April, the Academy would hold a dinner meeting at the Copley Plaza Hotel on April 17.

The following communication was presented

James Bryant Conant *Science and the National Welfare*

The meeting was dissolved at 9 45 P M.

One Thousand Three Hundred and Eighth Meeting

FEBRUARY 13, 1946 —STATED MEETING

The Academy met at the Old South Parish House Building at 8 20 P. M.

The President in the Chair

There were present thirty-five Fellows and four guests

In the absence of the Recording Secretary, the Corresponding Secretary served in his stead.

The records of the meeting of January 9 were read and approved.

Two new Fellows were introduced William A Jackson by Vice-President Robinson, and Talcott Parsons by the Corresponding Secretary.

The following amendments to the Statutes recommended by the Council at its January meeting were adopted by the Academy with no dissenting votes

CHAPTER II, Article 4, shall be amended to read· "If any person, after being notified of his election as Fellow, shall neglect for six months to accept in writing, or if a Fellow resident within fifty miles of Boston shall neglect to pay his Admission Fee *within six months* of his election, his election shall be void, and if any

Fellow resident within fifty miles of Boston shall neglect to pay his Annual Dues for six months after they are due, provided his attention shall have been called to this Article of the Statutes *by the Treasurer* in the meantime, he shall cease to be a Fellow

A non-resident Fellow, elected since 1938, who neglects to pay his Annual Dues for six months after they are due, and who ignores notification by the Treasurer of the requirement of this Article, shall cease to be a Fellow

But upon petition by the Fellow or by any officer of the Academy, the Council may by a majority vote suspend the provisions of this Article for any additional period of time not longer than three months "

CHAPTER II, Article 5 First paragraph Omit the clause: "unless previously as an Associate he has paid an Admission Fee of like amount " Second paragraph, second line: Omit the words "and others may "

CHAPTER IV, Article 1 Paragraph three, third line. Omit "on Resources and Policy" and substitute "on the Permanent Science Fund "

CHAPTER V, Article 1 For "the senior" in the second line, substitute "a " Omit the parenthesis ("seniority to be determined by length of continuous fellowship in the Academy").

Add as a new paragraph

"The President shall be the chief executive officer of the Academy. He shall present to the Council for its consideration all matters pertinent to the interests of the Academy and to the discharge of its obligations to the community or to the advancement of scholarship The President shall be Chairman of the Committee on Meetings "

CHAPTER VI, Article 1 Add a paragraph as follows

"He shall arrange for the preservation of records of the death of Fellows and biographical notices published on the occasion of their death, or at other times If existing notices are inadequate, he shall arrange for the preparation of a suitable biographical notice to be published in the Proceedings of the Academy or in some professional journal associated with the activities of the deceased Fellow."

CHAPTER VI, Article 2 Last paragraph, first line, substitute "any" for the second "the "

CHAPTER XI Omit paragraph (u) as it now stands and substitute the paragraph providing for a standing committee on the Permanent Science Fund, Omit paragraph (x).

CHAPTER XII, Article 7 Omit the present text and substitute the following:

"All amendments to the Statutes, whether proposed by Fellows or by the Council, shall be considered by the Council and reported with recommendations for action to the Academy. At a subsequent Stated Meeting, or at a Special Meeting called for the purpose, the notice for which in either case shall state this proposed amendment, the Academy shall act upon the amendment. Two-thirds of the Fellows present, in a meeting of not less than twenty-five Fellows, must vote in the affirmative to enact the amendment."

The following communication was presented

Edward Sagendorph Mason *The Economic Future of Germany*

The meeting was dissolved at 9 40 P. M

One Thousand Three Hundred and Ninth Meeting

MARCH 13, 1946 —STATED MEETING

The Academy met at its House at 8 25 P M

The President in the Chair

There were present forty Fellows and six guests

The records of the meeting of February 13 were read and approved

On the recommendation of the Council the following appropriations for the year 1946–1947 were voted

From the income of the General Fund, $9,200, to be used as follows

For House expenses	$3,600
for General and Meeting expenses	1,400
for Library expenses Salaries	2,400
Books, Periodicals & Binding	600
for Treasurer's expenses	1,200
Total	$9,200

It was also voted that the Editor, the Chairman of the Rumford Committee, and the Chairman of the C M Warren Committee be authorized to draw upon the balances available in their respective Funds.

The President announced that he had appointed the following as a Nominating Committee Bart J Bok, of Class I, *Chairman*, Ralph H Wetmore, of Class II, Douglass V Brown, of Class III, Michael J Ahern, S J , of Class IV

The following communication was presented

Kenneth V Thimann: *Growth Hormones in Plants* This was illustrated by lantern slides and by living material

The meeting was dissolved at 9 30 P M

One Thousand Three Hundred and Tenth Meeting

APRIL 17, 1946 —DINNER MEETING

The first annual dinner meeting of the Academy was held at the Copley Plaza Hotel on Wednesday, April 17, taking the place of the stated meeting on April 10.

One hundred and sixteen members were present, and the speakers were Dr Waldo G Leland, of the American Council of Learned Societies, and President Karl T Compton, of the Massachusetts Institute of Technology

At the request of the President, Mr. Robert Frost recited several of his poems

One Thousand Three Hundred and Eleventh Meeting

MAY 8, 1946 —ANNUAL MEETING

The Academy met at its House at 8 20 P. M.

The President in the Chair.

There were present fifty-eight Fellows and eleven guests.

The records of the meetings of March 13 and April 17 were read and approved

The Corresponding Secretary reported that the Council had voted to recommend to the Academy that the Statutes be amended to provide for the addition of the Amory Prize Committee to the list of standing committees.

He also read a resolution which the Council had adopted, copies of which are to be sent to the President of the United States, the President of the Senate, the Speaker of the House, the Senators from the Commonwealth of Massachusetts, and other academies in the United States of America, as follows

WHEREAS, whole populations in Europe and Asia face death by hunger if immediate and extensive help is not given them, and

WHEREAS, the loss to the world by starvation of scientists and scholars is of special concern to learned bodies; and

IN SO FAR as the food sent abroad from this country is neither in proportion to what we can spare nor adequate to the crisis,

Resolved, by the Council of the American Academy of Arts and Sciences, that we urge upon our government an increase in the amount of wheat, milk, and fats set aside to meet this emergency as well as an increase in the amount and speed of the transportation accorded this food, and

Resolved, that, voluntary rationing having proved inadequate, we urge a return to consumer rationing to assure both fair distribution of food in this country and adequate supplies for famine relief, and

Resolved, that copies of this resolution be sent to the President of the United States, the President of the Senate, the Speaker of the House, the Senators from the Commonwealth of Massachusetts, and other academies in the United States of America

The Corresponding Secretary announced that at its meeting on April 30 the Council had made the following grants from the Permanent Science Fund

1 To Charles F. Brooks, Director, Blue Hill Observatory, Harvard University, for completion of certain studies of cloud systems associated with storms in the eastern United States, $625

2 To Gregory Pincus, Director of Laboratories, Worcester Foundation for Experimental Biology, for assistance in a study of hormonal control of lymphocytes, $1,800

3. To A. H Reesor Smith, Lecturer, College of Engineering, University of California, as compensation for assistance contingent upon remaining necessary funds being secured otherwise for the synthesis of vinyl cyclopropane, $1,800.

4. To George Sachs, Professor of Physical Metallurgy, Case School of Applied Science, Cleveland, as compensation for assistance in the study of properties of thin metallic membranes, $900

5 To Irving M. Klotz, Instructor in Chemistry, Northwestern University, for assistance in his study of the interactions of proteins with organic molecules, $1,300

The Corresponding Secretary announced that the following had been elected members of the Academy

FELLOWS

CLASS I, SECTION 1

James Gilbert Baker	Waban
John Landes Barnes	Winchester
Subrahmanyan Chandrasekhar	Williams Bay, Wis

CLASS I, SECTION 2

Lee Alvin Du Bridge	Rochester, N Y
Julius Adams Stratton	Belmont

CLASS I, SECTION 3

Paul Doughty Bartlett	Weston
Walter Hugo Stockmayer	Weston

CLASS I, SECTION 4

William Loren Batt	Washington, D C
Howard Wilson Emmons	Sudbury

CLASS II, SECTION 1

Roland Frank Beers	Lincoln
Cornelius Searle Hurlbut, Jr	Belmont

CLASS II, SECTION 2

Ralph Erskine Cleland	Bloomington, Ind.

CLASS II, SECTION 3

George Wells Beadle	Palo Alto, Calif.
James Lee Peters	Harvard
Kenneth David Roeder	Medford

CLASS II, SECTION 4

John Franklin Enders	Boston
Charles Alderson Janeway	Weston
Siegfried Josef Thannhauser	Brookline

CLASS III, SECTION 2

Harvey Hollister Bundy	Boston
John Sloan Dickey	Hanover, N. H
Robert Burgess Stewart	Winchester

CLASS III, SECTION 3

Theodore Henry Brown	Cambridge
Harold Walter Stoke	Durham, N H

CLASS III, SECTION 4

Chester M Alter	West Newton
David Frank Edwards	Cambridge
Huntley Nowell Spaulding	Rochester, N H

CLASS IV, SECTION 1

Brand Blanshard	New Haven, Conn
Stanley Smith Stevens	Cambridge

CLASS IV, SECTION 2

Clarence Saunders Brigham	Worcester
Paul Herman Buck	Cambridge
Otto Eduard Neugebauer	Providence, R I

CLASS IV, SECTION 3

George Raleigh Coffman	Chapel Hill, N C
John Huston Finley, Jr	Cambridge

CLASS IV, SECTION 4

Edward Weeks, Jr	Boston
William Wilson Wurster	Boston

FOREIGN HONORARY MEMBERS

CLASS I, SECTION 1

Bertil Lindblad	Stockholm
Jan Hendrik Oort	Leiden

CLASS I, SECTION 4

Clarence Decatur Howe	Ottawa

CLASS II, SECTION 2

Rudolf Florin	Stockholm

CLASS III, SECTION 2

Winston Churchill	London

CLASS IV, SECTION 1

Francisco Romero	Buenos Aires

CLASS IV, SECTION 4

William George Constable	Cambridge, Mass

The following reports were then presented to the Academy

REPORT OF THE COUNCIL

Since the last report of the Council there have been reported the deaths of twenty-six Fellows and Fellows Emeriti: Thomas Barbour, Carl Lotus Becker, Edward Wilber Berry, William Crowell Bray, Walter Bradford Cannon, Charles Jay Connick, John Franklin Ebersole, Max Farrand, Simon Flexner, Edwin Francis Gay, Edwin Walter Kemmerer, Gilbert Newton Lewis, Leo Rich Lewis, John Livingston Lowes, Albert Matthews, John Campbell Merriam, Roger Bigelow Merriman, Thomas Hunt Morgan, William Allan Neilson, William Abbott Oldfather, William Morton Prest, Edward Kennard Rand, Theodore Leslie Shear, Carl Snyder, Harlan Fiske Stone, Jacob David Tamarkin, and two Foreign Honorary Members Ludwig Diels, and John Maynard Keynes Three Fellows have resigned· Frederic Adrian Delano, Wassily W Leontief, and Edward Sagendorph Mason, and the Fellowship of Manley Ottmer Hudson has been discontinued

Ten names have been added to the list of Fellows Emeriti Charles Thomas Brues, George Henry Chase, William Scott Ferguson, Henry Thatcher Fowler, William Hovgaard, Edward Felix Langley, Samuel Cate Prescott, Percy Edward Raymond, La Rue Van Hook, George Benson Weston

Thirty-three Fellows and five Foreign Honorary Members were elected by the Council and announced to Academy in May, 1945 All but William Lockhart Clayton and Howard Eugene Wilson accepted election

Not including those elected in 1946, the roll now includes 764 Fellows and 116 Foreign Honorary Members as well as 23 Fellows Emeriti

REPORT OF THE TREASURER

(Extract)

*RECEIPTS, 1945–1946

Academy, General			
Investment Income			
	$16,295 46		
Less Income to Special Funds	13,214 13		
		$3,081 33	
Assessments and Admission Fees		6,208 75	
			$9,290 08
Mabel S. Agassiz Fund			
Investment Income			116 70
Amory Prize Committee			
Investment Income			3,839 43
Kennelly Fund			
Investment Income			77 90
Life Membership Fund			
Robley D Evans			200 00
Permanent Science Fund			
Boston Safe Deposit and Trust Co., Trustee		$11,436 40	
Investment Income		1,517 10	
			12,953 50
Publications Committee			
Investment Income		$2,800 80	
Sale of Publications		513 81	
			3,314 61

* Excluding sales of securities

Rumford Committee			
Investment Income		$3,788 27	
Return of Grant		188 91	
			3,977 18
Special Expense Fund			
American Council of Learned Societies			1,000 00
Special Alterations Fund			
Contributions			760 00
C M Warren Committee			
Investment Income		$1,073 93	
Return of Grant		200 00	
			1,273 93
Total Receipts			$36,803 33

*EXPENDITURES, 1945 1946

Academy, General			
Library, Salaries	$2,228 00		
Books & Binding	632 38		
		$2,860 38	
General (Net)		1,416 41	
House (Net)		3,695 83	
Treasurer's Office		722 19	
Insurance	$1,445 84		
Less Unexpired Premiums	916 18	529 66	
			$9,224 47
Mabel S Agassiz Fund			
For Meetings			116 70
Amory Prize Committee			
Expense			38 90
Permanent Science Fund			
Grants		$900 00	
Expense		103 95	
			1,003 95
President's Special Expense Account			
Expense			55 00
Publications Committee			
General		$1,381 62	
Lake		1,838 65	
			3,220 27
Rumford Committee			
Grant		$250 00	
Rumford Memorial		25 25	
			275 25
Special Expense Fund			62 71
Special Alterations Fund			3,867 22
Warren Fund Committee			
Grants			505 00
Total Expenditures			$18,369 47

REPORT OF THE RUMFORD COMMITTEE

I have the report from the Treasurer which indicates that we have on hand a balance of $13,832 50, and that we have an estimated income for next year of about $3,800

Contribution to the present considerable balance comes from returns of earlier grants to the amount of $730 During the past year we made but a single expenditure $275 25

By general agreement we gave no Rumford medals this year on the grounds that we needed a little perspective with respect to the important wartime contributions before we next selected a man to honor

Respectfully submitted,
HARLOW SHAPLEY, *Chairman*

May 8, 1946

REPORT OF THE CYRUS M. WARREN COMMITTEE

The Committee had available for grants during the fiscal year 1945–1946 the sum of $1,000 which was appropriated at the March, 1945 meeting

The following grants were made after consideration of the applications submitted to the Committee·

To Professor Hugh J McDonald of the Illinois Institute of Technology, a grant of $205, for the purchase of a Beckman pH Meter to be used in connection with a study of the kinetics of dissolution of metals in various aqueous solutions

To Professor Pierre Van Rysselberghe of the University of Oregon, a grant of $300, to apply on the purchase of a Beckman Ultraviolet Spectrophotometer for use in the polarographic reduction of chlorophyll

A report was received from Mr Ralph N. Prince Textile Research Fellow, at the University of New Hampshire, in regard to a grant of $200 awarded in 1944 In a letter dated July 17, 1945, Mr Prince stated

"Although considerable preliminary work was done during the year, the press of other matters was so great, that no real progress was made on the proposed project A short report had been prepared for submission in May, however, at that time it was apparent that the work could not be continued in the near future Therefore the matter was held up until the exact situation could be determined

"It has developed that I shall not be located here at the Engineering Experiment Station after August 1st, and there will be little opportunity for me to continue the project in the near future

"Therefore, I have asked that the entire amount of the grant be returned to you I am attaching a copy of the preliminary report in addition to the check "

Respectively submitted,
FREDERICK G KEYES, *Chairman*

May 8, 1946

REPORT OF THE COMMITTEE OF PUBLICATION

No meeting of the Publication Committee was held during the year, such business as came up having been conducted by correspondence

The Index to Professor and Mrs Lake's *Dated Greek Manuscripts* was published during the year

* Excluding purchases of securities

This covers the ten fasciculi which have been published. If a supplementary fascicule should appear later, this will be separately indexed.

Professor Hatch's *Album of Dated Syriac Manuscripts* is in the press.

No new numbers of the *Proceedings* or of the *Memoirs* were published, but a manuscript by President Howard Mumford Jones has been accepted on the literature of colonial Virginia in the 17th century It is now being composed, and will be included in the *Memoirs*

Respectfully submitted,

ROBERT P BLAKE, *Chairman*

May 8, 1946

REPORT OF THE LIBRARY COMMITTEE

During the year 86 bound volumes were added to the library, making a total of 47,458 now on the shelves, of this number 79 were received by gift or exchange, and seven were purchased

In addition to the use of books in the building, 63 books and pamphlets were borrowed by 7 Fellows and 21 libraries

The appropriation for the year ending March 31, 1946, was $3,000, and the expenditures were as follows

Salaries	$2,228 00
Purchase of books and periodicals	450 43
Binding and repairing	181 95
Total	$2,860 38

No way has been found to mitigate the conditions of congestion, under-staffing and meagre use of our library pointed out in last year's report, and, in view of the accompanying severe deterioration of the building, the council has delegated a special committee to arrange the sale of our main stock of books and periodicals The economy resulting from cancellation of subscriptions and the assets potential in our extremely valuable holdings have meanwhile enabled the Building Committee to proceed without delay in its arduous work of rehabilitation

Meanwhile, we have devoted our attention to the following two operations

1 The identification and segregation of such early acquisitions as may properly be added to the archives of the Academy—chiefly the several hundred volumes of the Governor Bowdoin bequest To these are added books associated with the Founders and other distinguished early Fellows of the Academy, making a discrete collection of about 1000 volumes, the ultimate housing of which must depend upon what can be done to give them worthy protection and care We have had the valuable assistance of Mrs Anne Smith in the arrangement of this collection

2 The Librarian is by statute the custodian and distributor of the Academy's publications. These have of necessity accumulated unduly during the war, and we have been fortunate in securing the expert services of Mr. Richard Hoffman in sorting, packaging and packing for shipment the various consignments to the many exchanging and subscribing institutions here and abroad Your Committee have discussed at length, but tentatively, policies concerning publication and exchange that impending conditions must determine The likelihood of a new and wide demand on our store of past *Transactions* and *Memoirs* makes early attention to these holdings imperative

That Mr Metcalf, Mr Osborne and members of the Widener Library staff have shouldered the entire administrative and executive burden of checking the main collection of books, serials, and pamphlets, has alone made it possible for us to carry out the above programs

During the exceedingly trying conditions that have necessarily attended building repairs and alterations, the Assistant Librarian has continued the Academy's business without intermission, and we cannot but deeply appreciate Mrs Ball's persevering attention to the many and various demands of her office

Respectfully submitted,

FREDERICK HAVEN PRATT, *Chairman*

May 8, 1946

REPORT OF THE HOUSE COMMITTEE

During the year ending March 31, 1946, the House Committee faced a number of unusual difficulties These included the voluntary resignation of Thomas H Gately who had held the position of janitor for twenty-six years, and the engagement of Thomas Rodgate for this position Mr Gately was voted a monthly pension of $50 in view of his faithful service, and he was a guest of the Council at one of its dinner meetings

A large number of repairs were required by the recently enacted city safety regulations Moreover certain portions of the rear wall fell without warning, fortunately without injuring anyone, and had to be replaced, and certain other unusual repairs were necessary including the cleaning and waterproofing of the elevator pit, the installation of new grates in the furnace, and repairs to the elevator. The costs of some of these are being met by special funds and do not all appear in the expenditures listed below In addition to the necessary repairs, the Academy has improved the building by redecorating the interior and by removing the book stacks from the entrance lobby It has also installed alternating current electric power in order to provide an emergency lighting system.

Receipts from other societies using the building were materially reduced by the fact that the building was not available for many meetings on account of the repairs being made

As a result of the repairs and decorating, and because one of its regular meetings was replaced by a dinner meeting at the Copley Plaza Hotel, the Academy has held only two of its regular monthly meetings in its House. The other regular meetings of the Academy were held in the Mary Norton Hall of the Old South Parish House at the corner of Boylston and Dart-

mouth Streets The other societies holding meetings at the Academy building were. the New England Botanical Club, which held eight meetings in the Reading Room, the Boston Mineral Club, one meeting

The appropriation for House expenses for the year ending March 31, 1946, was $2,600, and during that period $180 was received from other societies for the use of facilities, making a total of $2,780, which was materially exceeded as a consequence of the foregoing unforeseen expenses

A detailed list of expenditures follows

Janitor	$1,136.13
Fuel	1,197 02
Electricity Light	278 30
Power	17 85
Elevator service and repairs	292.09
Telephone	146.85
Gas	42 24
Water	53 36
Upkeep	353 29
Janitor's supplies and sundries	81.70
Thomas H Gately's pension	250 00
Total	$3,878 83

Respectfully submitted,
CHARLES M SPOFFORD, *Chairman*

REPORT OF THE COMMITTEE ON THE PERMANENT SCIENCE FUND

The Committee on the Permanent Science Fund, appointed as a special committee by the Council on December 12, 1928, and yearly thereafter, has held semi-annual meetings without interruption since that date In May, 1945, by vote of the Council the probable permanency of this committee was recognized, and it was made a Standing Committee of the Academy. For the year 1945–1946 its personnel continued in ad hoc status pending the 1946 election of officers and committees

During the twelve months since May, 1945, the Committee has considered seventeen applications, of which five were recommended to and approved by the Council for grants-in-aid totalling $6,425 00

The devotion of efforts of scientists to the prosecution of the war has reduced the volume of applications for aid addressed to this Committee to one in October, 1945, a circumstance which is unique in its seventeen years of continuous experience

Notices of the nature and availability of the Permanent Science Fund were thereupon furnished to the editors of 28 journals representing a wide coverage of natural, social and mathematical sciences, in the United States, Canada and Britain

The Permanent Science Fund endowment was reported by its Trustee to amount to about $315,000 in 1944. Income from this fund is paid semi-annually to the Academy, designated in the Indenture of Trust as the disbursing agent therefor Accumulated income is invested by our own Treasurer and its earnings added to its accumulations, which as of March 31, 1946, are of the order of $47,000, of which the last yearly increment received from the Trustee was slightly more than $11,000, and our earnings on our accumulations for the year were of the order of $1,500. The precise figures are presented in the report of the Treasurer.

With the accumulations in hand and the useful size of the yearly income in sight, the Permanent Science Fund Committee is in a position to aid worthwhile projects in a significant way for the advancement through science of human welfare

Respectfully submitted,
JOHN W M. BUNKER, *Chairman*

May 8, 1946

On the recommendation of the Treasurer, the Academy voted that the annual assessment for the year 1946–1947 for resident Fellows be fifteen dollars

The annual election of officers and committees resulted as follows

Howard M. Jones	*President*
Roland G D Richardson	*Vice-President for Class I*
John W M. Bunker	*Vice-President for Class II*
Erwin N Griswold	*Vice-President for Class III*
Donald Scott	*Vice-President for Class IV*
Lewis Don Leet	*Corresponding Secretary*
Isadore Amdur	*Recording Secretary*
Horace S Ford	*Treasurer*
Frederick H Pratt	*Librarian*
Taylor Starck	*Editor*

COUNCILLORS FOR FOUR YEARS

Philip Franklin	Class I
Frederick K Morris	Class II
Charles E. Wyzanski, Jr.	Class III
John G Beebe-Center	Class IV

COMMITTEE ON PERMANENT SCIENCE FUND

John W M Bunker, *Chairman*

Roger Adams	Albert B Hastings
Kirk Bryan	Edward L Moreland
Lee A DuBridge	Payson S Wild, Jr

FINANCE COMMITTEE

Jerome C Hunsaker	Henry P Kendall
Ralph E Freeman	Henry L. Shattuck

RUMFORD COMMITTEE

Harlow Shapley, *Chairman*

Percy W. Bridgman	Joseph H. Keenan
Harry M Goodwin	Francis O. Schmitt
George R Harrison	Edwin H. Land

C M WARREN COMMITTEE

Frederick G Keyes, *Chairman*

Louis F. Fieser	Avery A. Morton
Charles A Kraus	Walter C. Schumb
Grinnell Jones	Kenneth L. Mark

COMMITTEE OF PUBLICATION

Taylor Starck, *Chairman, ex officio*

Ernest H Huntress	Class I
Kenneth V. Thimann	Class II
Thomas North Whitehead	Class III
Kenneth J Conant	Class IV

COMMITTEE OF THE LIBRARY

Frederick H. Pratt, *Chairman ex officio*

Raymond C Archibald	Class I
Charles A Weatherby	Class II
Francis N Balch	Class III
Henry B Washburn	Class IV

AUDITING COMMITTEE

Donald S. Tucker — Thomas H Sanders

HOUSE COMMITTEE

Charles M. Spofford, *Chairman*

H Addington Bruce — Robert P Bigelow

John B Wilbur

COMMITTEE ON MEETINGS

The President

The Recording Secretary

Edgar S. Brightman — Cecilia Payne-Gaposchkin

Crane Brinton — Seymour E. Harris

The general subject of the communication was *The Ecological Approach to Land Use,* treated by three speakers, as follows

Edward H. Graham: *The Ecologists' Viewpoint*

Seymour E Harris *The Economists' Viewpoint*

Edward A. Ackerman. *The Geographers' Viewpoint.*

The meeting was dissolved at 10 30 P M

One Thousand Three Hundred and Twelfth Meeting

OCTOBER 9, 1946.—STATED MEETING

The Academy met at its House at 8.20 P M

The President in the Chair

There were present sixty Fellows and fourteen guests.

The records of the meeting of May 8 were read and approved.

A vote was taken on a proposed amendment to the Statutes, Chapter XI, Article 2, which had been recommended to the Academy by the Council at the annual meeting last May The amendment called for the addition of the Committee on the Amory Prize to the Standing Committees of the Academy by insertion in Chapter XI, Article 2, of the Statutes, of the following

The Committee on the Amory Prize, to consist of seven Fellows, who shall consider all persons eligible for this award and recommend to the President and Fellows of the Academy a suitable recipient of the award according to the terms of the gift

The amendment was adopted unanimously

The Rev. M J. Ahern, S J, representative of the Academy at the observance of the one-hundredth anniversary of the Fine Arts Section of the Royal Belgian Academy of Sciences and Letters in Brussels, July 24–27, reported to the Fellows and guests He presented to the President, for the Academy, a medal from the Belgian Academy

The Corresponding Secretary reported the receipt of letters accepting Fellowship from the following Chester M. Alter, James Gilbert Baker, John Landes Barnes, Paul Doughty Bartlett, George Wells Beadle, Roland Frank Beers, Brand Blanshard, Clarence Saunders Brigham, Theodore Henry Brown, Harvey Hollister Bundy, Subrahmanyan Chandrasekhar, Ralph Erskine Cleland, George Raleigh Coffman, John Sloan Dickey, Lee Alvin Du Bridge, David Frank Edwards, Howard Wilson Emmons, John Franklin Enders, Cornelius Searle Hurlbut, Jr, Charles Alderson Janeway, Otto Eduard Neugebauer, James Lee Peters, Kenneth David Roeder, Huntley Nowell Spaulding, Stanley Smith Stevens, Robert Burgess Stewart, Walter Hugo Stockmayer, Harold Walter Stoke, Julius Adams Stratton, Siegfried Josef Thannhauser, Edward Augustus Weeks, Jr., William Wilson Wurster; and of letters accepting Foreign Honorary Membership from Winston Churchill, William George Constable, Rudolf Florin, Clarence Decatur Howe, Bertil Lindblad, Jan Hendrik Oort, and Francisco Romero; also letters declining Fellowship from Paul Herman Buck and John Huston Finley, Jr

The President announced that at the November meeting, the Academy would go into a Committee of the Whole to consider the Report of the Commission on the Present Status and Future of the Academy

He also made preliminary announcements concerning the February conference on The Artist in American Society.

New members were introduced by sponsoring Fellows

The following communication was presented

William A. Jackson: *Forgeries and Facsimiles.*

One paper was presented by title *Lower Permian Insects from Oklahoma. Part 1,* by F M Carpenter

The meeting was dissolved at 9.45 P. M

One Thousand Three Hundred and Thirteenth Meeting

NOVEMBER 13, 1946.—STATED MEETING

The Academy met at its House at 8 25 P M

The President in the Chair

There were present sixty-six Fellows and one guest.

The records of the meeting of October 9 were read and approved

The President announced the inaugural lecture of The Arthur Dehon Little Memorial Lectureship series to be given by Sir Edward V. Appleton at the Massachusetts Institute of Technology, November 19, 1946. Members of the Academy were invited to attend

New members were introduced by sponsoring Fellows

It was moved that the Fellows present constitute a Committee of the Whole to consider the Report of the Commission on the Present Status and Future of the Academy The motion was carried

The President appointed Dean George R Harrison chairman of the Committee of the Whole The Recording Secretary acted as secretary of the Committee It was pointed out by the chairman that action by the Committee of the Whole would take the form of favorable or adverse recommendation to the Council and Academy

Kirtley F Mather, chairman of the Commission, summarized the report and listed the following priorities which had been assigned by the Commission to its recommendations

First—Increase in Membership (pp 19–21 of Report)

Second—Establishment of a Committee on Nominations (pp 21–22 of Report)

Third—The focus of attention upon the regional responsibilities of the Academy (pp 17–19 of Report)

Fourth—Creation of the position of Executive Officer (pp 37–38 of Report)

Fifth—Changes in publication policy (pp 31–35 of Report)

Sixth—Acceptance of responsibility for leadership in formation of public opinion on matters of import to the body politic (pp. 14–16 of Report)

Seventh—Creation of a committee for the award of prizes or medals to outstanding younger American scholars (pp. 40–41 of Report)

The following recommendations were mentioned for future discussion without assignment of priorities

Changes in the character of meetings of the Academy (pp 22–28 of Report)

Additional changes in the House of the Academy (pp 28–29 of Report)

Greater use of the Academy's House by outside organizations (pp 30–31 of Report).

Sale of portions of the Library (pp 35–36 of Report). (The majority of recommendations concerning the Library have already been realized as of this date)

Support of expanded program by additional income resulting from the sale of the Library and by dues from the increased number of Fellows (pp. 38–39 of Report)

The following actions were taken by the Committee of the Whole

1 It was moved that the Committee report favorably on the recommendation that "the number of Fellows shall not exceed 1000, of whom not more than 700 shall be residents of Massachusetts, nor shall there be more than 275 in any one Class "

In the discussion it was pointed out that the reduction of the percentage of Fellows from Massachusetts from 75 per cent to 70 per cent was intended to broaden the base of the membership, and that the primary purpose of the recommendation was to add vitalizing Fellows to the Academy membership and not to obtain additional revenue

The motion was carried

2 It was moved that the Committee report favorably on the recommendation calling for "the establishment of a Standing Committee on Nomination of Fellows and Foreign Honorary Members, consisting of two Fellows from each Class, not members of the Council, to be elected at the Annual Meeting for terms of two years, with the elections so arranged that one member of the Committee will be elected each year from each Class, and with the President of the Academy serving ex officio as the Chairman of the Committee "

It was moved that the original motion be amended to favor a Committee consisting of four Fellows from each Class, chosen one each from the four Sections, and that this representation be preserved when filling vacancies in the Committee The motion to amend was lost

In the discussion it was pointed out that the creation of a standing Committee on Nomination of Fellows and Foreign Honorary Members is not intended to replace but to supplement existing nomination procedures

The original motion was carried

3 It was moved that the Committee report favorably on the recommendation that the Fellows "focus atten-

tion upon the regional responsibilities of the Academy, but do not be unmindful of its national interests "

The motion was carried

In the discussion of a suggestion for a regional study of New England, it was pointed out that outside financial support and qualified administrative personnel would be required for surveys as outlined in the Report of the Commission. It was also pointed out that since the living problems of New England have social and political implications and are therefore certain to become controversial at times, the Academy should be prepared to become involved in such controversies if it acts favorably on this suggestion of the Commission

4. It was moved that the Committee report favorably on the recommendation calling for "the establishment of the position of Executive Officer of the Academy" whose duties are described in the Report of the Commission

In the discussion, the type of person required for this position was described It was pointed out that the Treasurer was of the opinion that funds would be available, chiefly as the result of the sale of the Library, to pay a salary sufficient to attract an Executive Officer of the proper qualifications

The motion was carried

The Committee of the Whole rose to report at 10 30 P M and then dissolved

The meeting was dissolved at 10 35 P M

One Thousand Three Hundred and Fourteenth Meeting

DECEMBER 11, 1946.—STATED MEETING

The Academy met at its House at 8 17 P M

The President in the Chair

There were present forty-nine Fellows and six guests

The records of the meeting of November 13 were read and approved

The President announced the appointment of John W. M. Bunker as Corresponding Secretary to succeed L. Don Leet, whose new duties outside the state have necessitated his resignation as Corresponding Secretary Dean Bunker will serve until the next duly elected incumbent takes office

The Corresponding Secretary reported on the actions taken by the Council at its meeting of this date.

New members were introduced by sponsoring Fellows

The President announced that the speaker for the January meeting would be Professor Brand Blanshard of Yale University, who would speak on certain aspects of man's ability to comprehend the rapidly increasing store of human knowledge

The President informed the members that four panel discussions had been planned for the February National Conference on the Support of the Visual Arts and that admission would be by ticket He stated that the members would be informed shortly of the complete program for the conference, and of the method of applying for admission tickets

The following communication was presented

Julius A Stratton *Electronics in War and Peace*

The meeting was dissolved at 9 55 P M

One Thousand Three Hundred and Fifteenth Meeting

JANUARY 8, 1947 —STATED MEETING

The Academy met at its House at 8 25 P M

The President in the Chair

This meeting had been designated as Ladies' Night, and there were present about one hundred and twenty-five Fellows and guests

The records of the meeting of December 11, 1946 were read and approved

The Corresponding Secretary, on behalf of the Special Committee on Statutory and Legislative Changes, presented a motion recommending that the Academy rescind the current Standing Votes 1-4 inclusive, since they are no longer operative The motion was carried unanimously

A new member was introduced by a sponsoring Fellow

The President outlined the final program for the February National Conference on the Support of the Visual Arts and reminded members to apply for tickets to the scheduled panel discussions

The following communication was presented

Brand Blanshard *Can Man Expand with Expanding Knowledge*

The meeting was dissolved at 9 40 P M

One Thousand Three Hundred and Sixteenth Meeting

FEBRUARY 14 and 15, 1947 —STATED MEETING

The Academy met at its House

The President opened the meeting

The meeting had been designated as the "Conference on the Artist in Contemporary American Society" and there were present about

one hundred and seventy Fellows and invited guests The Conference was divided into four panel discussions, each with six scheduled speakers, as follows

February 14:

10·00 A. M —12.30 P M Panel Discussion I: *What does the buyer want from the artist?* Chairman, Charles S. Sawyer, Worcester Art Museum

2 30—5:00 P M Panel Discussion II *Can the artist supply what is wanted?* Chairman, Edward A Weeks, The Atlantic Monthly.

February 15:

10·00 A M —12:30 P M Panel Discussion III. *The problem of marketing agencies* Chairman, Bartlett H Hayes, Jr, Addison Gallery

2·00 P. M —4 30 P. M Panel Discussion IV *The artist and the community the problem of interaction* Chairman, Howard Mumford Jones

At 8 30 P M. on February 14, W G Constable, Boston Museum of Fine Arts, delivered a public lecture entitled, *Art and Everyday Life*

In conjunction with the Conference, an exhibition was arranged on the first floor of the Academy, to illustrate the way in which typical problems within various industries are handled by the contemporary industrial designer The exhibition was organized by the Institute of Modern Art, Boston, and was open to the public Monday through Friday afternoons for four weeks beginning February 17

One Thousand Three Hundred and Seventeenth Meeting

MARCH 12, 1947 —STATED MEETING

The Academy met at the Colonial Room of the Copley Plaza Hotel at 7.15 P M

The President in the Chair

This meeting had been designated as the Second Annual Dinner meeting and there were present seventy-seven Fellows, seven of whom were honored guests, and five non-member honored guests.

The President introduced the honored guests He announced appointment of the Nominating Committee as follows.

Philip Franklin, of Class I, *chairman*

Louis C. Graton, of Class II

Abbott P. Usher, of Class III

Paul J. Sachs, of Class IV

The Corresponding Secretary presented recommendations voted by the Council at a special meeting on March 11. The recommendations were in response to a report by the Treasurer and provided for.

1. Use of funds to the amount of $1,291, from the sale of the Library, to offset the deficit in over-all operations for the fiscal year 1946–1947.

2 Specified appropriations for the fiscal year 1947–1948 as follows·

for House expenses	
Operating	$ 5,600
Meetings	2,500
Stenographer	2,100
for Library expenses:	
Salaries	3,000
Other	500
for Treasurer's expense	1,500
for President's expense	600
Amory Fund	500
Thomas Barbour Fund	250
Kennelly Fund	75
Permanent Science Fund	2,000
Publication Committee Fund	1,000
Rumford Fund	4,000
Warren Fund	1,000
Total	$24,625

The recommendations were approved as presented

The Corresponding Secretary moved that the Academy approve a bill for presentation to the present session of the General Court to amend the Academy Charter The bill would enable the Academy to determine the size of its membership and to pass regulations concerning election, discipline and expulsion of members The motion was carried

The Corresponding Secretary informed the members of the action of the Council to favor operation on yearly appropriations, without carry over of unexpended balances. This policy calls for advance appropriations for foreseeable expenses to the Standing Committees, which may apply to the Council for additional appropriations He also stated that all occupants of the House of the Academy will share in the operating expense.

The Recording Secretary announced that a symposium on the Science Talent Search was planned for the April meeting.

The President reviewed recent Academy activities and urged greater participation by the

members in the affairs of the Academy. He announced the receipt of a gift of $5,000 to be known as the Barbour Fund, the income of which is available for general purposes.

The following communications were presented.

I. A. Richards: *The Language of the Specialist*

William H. Davis: *The Art and Science of Labor Relations.*

The meeting dissolved at 10.40 P. M.

One Thousand Three Hundred and Eighteenth Meeting

APRIL 9, 1947.—STATED MEETING

The Academy met at its House at 8.20 P. M

The President in the Chair.

There were present twenty-five Fellows and twenty-eight guests

The records of the meetings of January 8, February 14 and 15, and March 12 were read and approved.

The Recording Secretary reported on the Initiating Meeting of the Inter-Society Committee on Science Foundation Legislation held in Washington on February 23 He also gave the results of a poll dated March 13, of delegates to the Inter-Society Committee, on questions of composition, policies, and program of a National Science Foundation

Bart J. Bok, representative of the Academy at the first National Conference on UNESCO held in Philadelphia on March 24-26, reported on the results of the conference

The Corresponding Secretary announced that the Council had started consideration of the recommendations of the Committee on Revision of the Statutes at its April meeting and planned to complete the discussion at its May meeting He announced that the report to the Fellows would be made at the October meeting

The general subject of the communication was the *National Science Talent Search* The speakers were Harlow Shapley, Watson Davis, and Fletcher G. Watson.

At the conclusion of the discussion of the communication, it was moved and seconded that "It is the sense of this meeting that the American Academy of Arts and Sciences should concern itself with the discovery, encouragement, and development of latent scientific talent in New England and especially in Massachusetts. It is therefore recommended that a Committee be formed under the auspices of the American Academy of Arts and Sciences, which will be broadly representative of all groups interested in science education at the secondary school level, and that this Committee be instructed to explore ways for encouraging our potential young scientists."

The motion was carried.

The meeting dissolved at 10.25 P. M.

One Thousand Three Hundred and Nineteenth Meeting

MAY 14, 1947 —ANNUAL MEETING

The Academy met at its House at 8·30 P M

The President in the Chair.

There were present forty-three Fellows and seven guests.

The records of the meeting of April 9 were read and approved

The Corresponding Secretary read the names of the newly elected members of the Academy, as follows·

FELLOWS

CLASS I, SECTION 1

Howard Hathaway Aiken	Newton

CLASS I, SECTION 2

Hans Albrecht Bethe	Ithaca, N Y
Edward Uhler Condon	Washington, D. C

CLASS I, SECTION 3

Paul Clifford Cross	Providence, R I
Clark Conkling Stephenson	Cambridge

CLASS I, SECTION 4

Charles Winters MacGregor	Belmont

CLASS II, SECTION 3

Arnold Gesell.	New Haven, Conn

CLASS II, SECTION 4

Arthur Wilburn Allen	Brookline
David Lawrence Belding	Boston
Sanford Burton Hooker	West Roxbury
Francis Minot Rackemann	Boston
James Stevens Simmons	Brookline
Richard Mason Smith	Boston
Merrill Clary Sosman	Chestnut Hill
Shields Warren .	West Newton

CLASS III, SECTION 1

Mark DeWolf Howe	Cambridge
John Lord O'Brian	Washington, D. C

CLASS III, SECTION 2

William Phillips.	North Beverly
Sumner Welles	Oxon Hill, Md

CLASS III, SECTION 3

George Pierce Baker	Boston
Fritz Jules Roethlisberger	Cambridge

CLASS III, SECTION 4

Thomas Dudley Cabot	Weston
William Henry Claflin, Jr.	Belmont
Mildred McAfee Horton	Wellesley
Ralph Lowell	Westwood

CLASS IV, SECTION 1

Norman Burdett Nash	Boston

CLASS IV, SECTION 2

Ruth Fulton Benedict	New York, N. Y
Wilbur Kitchener Jordan	Cambridge

CLASS IV, SECTION 3

Ivor Armstrong Richards	Cambridge
William Freeman Twaddell	Providence, R I

CLASS IV, SECTION 4

Richard Burgin	Brookline
John Dos Passos	Provincetown
Milton Edward Lord	Boxford
Lewis Mumford	Amenia, N Y

FOREIGN HONORARY MEMBERS

CLASS I, SECTION 1

Edward Arthur Milne	Oxford
Meghnad Saha	Calcutta
G A Shajn	Simeis, U S S R
Ivan Matveitch Vinogradoff	Moscow

CLASS I, SECTION 2

Sir George Paget Thomson	London

CLASS II, SECTION 1

Wen-hao Wong	Nanking

CLASS II, SECTION 2

P. Maheshwari	Dacca, India
Alf Erling Porsild	Ottawa

CLASS II, SECTION 3

Augustus Daniel Imms, Tipton St John's, Devonshire

CLASS III, SECTION 1

Paal Berg	Oslo

CLASS IV, SECTION 1

Godfrey Hilton Thomson	Edinburgh

CLASS IV, SECTION 3

Hamilton Alexander Rosskeen Gibb	Oxford
Joseph Klausner	Jerusalem

The following annual reports were read and approved·

REPORT FROM THE COUNCIL

Since the last report of the Council, there have been reported the deaths of twenty-three Fellows: Wilfred Bolster, Willa Sibert Cather, Henry Helm Clayton, Irving Fisher, Allyn Bailey Forbes, Roger Sherman Greene, Hammond Vinton Hayes, William Clifford Heilman, Edward Godfrey Huber, Carl Newell Jackson, Herbert Spencer Jennings, Willis Linn Jepson, Kirsopp Lake, Henry Lefavour, Edward Laurens Mark, Albert Davis Mead, John Anthony Miller, Curtis Hidden Page, Leo S Rowe, William Berryman Scott, Horatio Elwin Smith, Bentley Wirt Warren, Westel Woodbury Willoughby; and of five Foreign Honorary Members: Miguel Asin y Palacios, Sir Joseph Barcroft, William Warwick Buckland, Pierre Janet, and Friedrich Paschen. Four Fellows have resigned. Howard Sylvester Ellis, Gottfried Haberler, Perry Gilbert Eddy Miller, and Harold Glenn Moulton

Six Fellows have been classed as Emeriti: Reginald Aldworth Daly, Joseph Horace Faull, Sidney Bradshaw Fay, James Geddes, Jr, Charles Howard McIlwain, and George Edmond Russell.

One transfer has been made from Foreign Honorary Member to Fellow William George Constable

In May 1946, the election by the Council of thirty-five Fellows and seven Foreign Honorary Members was announced to the Academy: all except three of these accepted election.

The roll now includes 764 Fellows, 29 Fellows Emeriti and 116 Foreign Honorary Members (exclusive of those elected in 1947).

The Academy is informed that its petition introduced into the House and the Senate of Massachusetts to amend the Act which governs the number of members of the Academy will be given a hearing on May 19, 1947, at which officers of the Academy will be present

The Council has voted that consideration of proposed amendments to the Statutes of the Academy will be the principal order of business of the stated meeting of the academy in October, 1947.

REPORT OF THE TREASURER

(Extract)

*RECEIPTS, 1946–1947

Academy, General			
Investment Income			
	$13,673.06		
Less: Income to Special Funds	13,776 36		
		$4,896 70	
Assessments and Admission Fees		6,460 00	
			$11,356 70
Mabel S. Agassiz Fund			
Investment Income			108.40
Amory Prize Committee			
Investment Income .			3,956.60
Thomas Barbour, Bequest from Estate of			5,000 00
Carnegie Corporation, for Visual Arts Conference..			2,000.00

* Excluding sales of securities

Kennelly Fund		
Investment Income ..		$75.88
Life Membership Fund		
From Eric G. Ball		200.00
Permanent Science Fund		
Boston Safe Deposit and Trust Co., Trustee	$11,333.74	
Investment Income	1,788 60	
		13,122 34
Publications Committee.		
Investment Income	$2,710.00	
Sale of Publications	696.61	
Lake Publications	276 05	
		3,682 66
Rumford Committee		
Investment Income	$4,139 60	
Return of Grant	30 74	
		4,170 34
Library Sale Fund		
From Linda Hall Library Trustees		140,000.00
Special House Alterations Fund		
Contributions and Sales		168.50
C. M. Warren Committee		
Investment Income		997 28
Total Receipts		$184,838 70

*Expenditures, 1946–1947

Academy, General			
Library, Salaries.	$2,492 00		
Books & Binding	413 14		
		$2,905 14	
General (Net)		2,773.91	
House (Net)		5,014 33	
President's Expense		224 93	
Treasurer's Expense (Net)		851 92	
Insurance	$1,157 63		
Less Unexpired Premiums	635 20	522 43	
			$12,292 66
Mabel S Agassiz Fund			
For Meetings			108 40
Amory Prize Committee			
Expense			76 50
Carnegie Corporation, for Visual Arts Conference			2,131 82
Permanent Science Fund			
Grants		$8,625 00	
Expense		9.50	
			8,634 50
Publications Committee			
General		$821.04	
Lake		12.56	
Hatch		2,690.19	
			3,523.79
Rumford Committee			
Grants			800 00
Library Sale Fund			
Boxes and Express			$2,109 67
Special Expense Fund (Mather Committee)			327 37
Special House Alterations Fund			15,378 55
C M Warren Committee			
Grants			1,000 00
Total Expenditures			$46,383 26

* Excluding purchases of securities

REPORT OF THE RUMFORD COMMITTEE

Three research grants have been made

To Dr Leo L Baranek, Cruft Laboratory, Harvard University, to assist in researches on the transfer of acoustic energy into heat energy in samples of fibrous materials, such as cotton, kapok, and Fiberglas $400

To Dr O Oldenberg, Physics Laboratory, Harvard University, to assist in the investigation of the kinetics of free hydroxyl radicals, $400

To Dr Willem J Luyten of the University of Minnesota, to assist in researches on the motions and luminosities of dwarf binary stars, $250

One application is pending Unused remainders of grants have been returned from F Schlesinger, C T Elvey, D K Fromm, and G Z. Dimitroff, in the total amount of $764 98

The balance in the Rumford Fund available on this date for the use of the Committee is nearly seventeen thousand dollars, and the Treasurer estimates the income for 1947–1948 will be $4,120

The Committee plans to consider the advisability of making larger grants in aid of reserach than has heretofore been the custom For several years we have limited our grants to four hundred dollars and less.

The Committee is in the process of selecting a candidate for the Rumford Medals, to be awarded at some meeting of the Academy during the year 1947–1948

Satisfactory reports have been received from some Rumford Fund grantees The Committee is in the embarrassed possession of a valuable diamond which has been returned by a grantee whose researches no longer require this accessory The Council may wish to decide what officer or agency should be designated keeper of the Academy's jewels

Respectfully submitted,

Harlow Shapley, *Chairman*

May 14, 1947

REPORT OF THE CYRUS M. WARREN COMMITTEE

The Committee had available for grants during the fiscal year 1946–1947 the sum of $1,000 00, which was appropriated at the March, 1946 meeting

The following grants were made after consideration by the Committee of the applications submitted

To Professor I. Amdur of the Massachusetts Institute of Technology, a grant of $300 for the purchase of

pure deuterium gas to be used in extending his research on scattering of high velocity hydrogen atoms by hydrogen molecules to systems involving all possible combinations of atoms and molecules of deuterium as well as atoms and molecules of hydrogen

To Professor Edward R Atkinson, University of New Hampshire, a grant of $400 to be used toward the purchase of a Heyrovsky Polarograph for use in connection with research on the action of reducing agents on diazotized amines

To Professor Pierre Van Rysselberghe, University of Oregon, a grant of $300 to be applied on the purchase of an electric analyzer and two sets of platinum electrodes, items needed for continuation of research in the field of solutions

A letter was received from Professor E C Gilbert of Oregon State College reporting on a 1940 grant from the Cyrus M Warren Fund The thermometer bridge purchased by the aid of a grant is functioning but there has been delay in publication of the material Reprints will be forthcoming shortly

A report from Professor Atkinson states that the polarograph has been in daily use and that a paper based on work with the instrument will be presented at the American Chemical Society meeting in New York in September

Professor Amdur reports that the pure deuterium gas has been obtained and the research is still in progress. It is expected that experimental results will be available during the coming year.

Reprints have been received as follows

Studies on Film-Forming Yeasts Acid Production by Zygopichia and Zygohansenula by Walter J Nickerson. Mycologia, *36*, 224–233 (1944)

On the Metabolism of Zygosaccharomyces by Walter J Nickerson and William R Carroll Archives of Biochemistry, *7*, 257–271 (1945)

Respectfully submitted,
FREDERICK G KEYES, *Chairman*

May 14, 1947

REPORT OF THE COMMITTEE OF PUBLICATION

The Committee has held only one meeting during the year, this a fairly long one, but a considerable amount of work was done by correspondence, since it seemed difficult to get all the members together more frequently As only a few papers were submitted for publication, regular meetings were hardly needed.

The most considerable publication issued was the *Album of Dated Syriac Manuscripts* by W. H P. Hatch All the editorial work in this volume was done by the previous Editor of Publications. The volume was ready except for title page, binding, and cover jacket, and the final arrangements with the Harvard University Press. The Harvard University Press according to an earlier contract undertakes the marketing of the book and distributes review copies The binding was delayed for a number of months because of shortage of materials, but the volume finally appeared early in 1947. Review copies have been distributed.

Late in 1946 Howard M Jones, *The Literature of Virginia in the Seventeenth Century* appeared as Memoirs, Volume XIX, Part 2 This had been accepted in the year 1945–1946 and was partially in type when the incumbent editor assumed office

One number of the Proceedings, Volume 76, No 2, was accepted and published, a continuation of Frank M Carpenter's study of *Permian Insects from Oklahoma*

As a special publication the Committee accepted the account of the panel discussion on the *Ecological Approach to Land Use* held at the Academy's meeting of May 8, 1946. This had been printed in the *Journal of Soil and Water Conservation*, Volume I, No 2 (October, 1946). Offprints were made and provided with a special cover and made available to Fellows

Furthermore, the editor carried out the policy inaugurated last year of having planographed and distributed abstracts of the communications to the Academy In this series was included a summary of the Report of the Conference on the Support of the Visual Arts held at the Academy's House on February 14 and 15, 1947

No action is pending on any manuscript and nothing is in press. Pending are negotiations for the possible publication of a *Study of Massachusetts Facilities for Child Health* carried through by the American Pediatric Association A meeting has been arranged for May 14 which will perhaps result in a proposal to be laid before the Editorial Committee

The Publication Accounts were submitted by the Treasurer as of March 12, 1947 They show an overdraft of $2,182 90 in the Hatch Account but a credit balance of $9,902 79 in the General Account and a credit balance of $1,590 81 in the Lake Account By Council action on March 11, 1947, these accounts have all been consolidated and $1000 appropriated for the initial publication expenditures for 1947–1948 The funds in sight are therefore ample for normal publication activities

Respectfully submitted
TAYLOR STARCK, *Chairman*

May 14, 1947

REPORT OF THE LIBRARY COMMITTEE

We submit the following statement of account

Appropriated	
Salaries	$2,700.00
Books, Periodicals, Binding	600 00
	$3,300.00
Expended	
Salaries	$2,492.00
Binding	164.90
Repair	111.00
Books of reference	137.24
	$2,905.14

Funds appropriated to the library have long covered several fields: first, the care and circulation of books, serials and pamphlets, represented in the salary of the Assistant Librarian, secondly, the filling and dispatch of completed publications and the reception of items exchanged or subscribed for, including their binding, again implemented by the same salary, third, the operation of the Academy's central office, subject to the needs of its officers, such as handling current announcements, roll of membership, collection of dues, telephone service, and items arising in connection with meetings and outside organizations—these also devolving upon the versatility of the Assistant Librarian And it should not be forgotten that for many years that office has had, in the oversight of nearly 50,000 volumes, the sole assistance of the resident custodian of the building, separately supported by the building appropriation—these together constituting the library staff.

Economies effected by present changes are important, though as yet few Periodical subscriptions have been virtually eliminated From now on there will be bills for essential reference works, but none for binding other than of our own publications. Repair work on books, for years at a standstill, no longer threatens the treasury But against these economies the library must for the time being shoulder one increase in expenditure—that of extra employment. During the concurrent renovation of the building and dismantling of stacks, the office has been sorely taxed to meet the world-wide renewal of demand for our publications, so long dammed up by war The work of checking, sorting and shipping this material is arduous and requires specific skilled attention. This demand has fortunately been met by Mr. Richard Hoffman's experienced service, and such abilities will be required as long as the present organization of our exchange program continues.

A collection of about 850 volumes, the gift of founders and other early donors, awaits distribution to special libraries or appropriate depositories, with the desirability in mind of retaining certain items of special historical significance, some of which have been restored with great skill by Miss Irene Tilden The majority of the volumes, the bequest of Governor Bowdoin, is fittingly destined for deposit in the James Bowdoin collection at Bowdoin College We are grateful to Mrs. Anne Smith, who has always stood ready to serve in emergencies (as during Mrs Ball's recent unfortunate wrist injury) for her interest and efficient aid in listing and arranging all of these ancient treasures.

Respectfully submitted,

FREDERICK HAVEN PRATT, *Chairman*

May 14, 1947

REPORT OF THE HOUSE COMMITTEE

At the request of the Lowell Institute Cooperative Broadcasting Council, office space of 1200 square feet has been provided on the fourth floor of the Academy House by removing the bookcases and books formerly occupying the westerly portion of this floor, the walls have been redecorated, the floor refinished and fluorescent lighting fixtures installed, making the quarters for the Council highly satisfactory One-half of the cost of the repairs is to be paid by the Institute which also pays a reasonable amount towards maintenance Prior to the allotment of this space the Council staff used the Reception Room on the Ground Floor

The packing of books for shipment to the Linda Hall Library in Kansas City, as per contract, has been nearly completed Due to the lack of storage space in Kansas City, the Academy has temporarily stored a considerable number of packed books in boxes

During the year of 1946–1947 meetings have been held in the Academy Building as follows

Antiques Committee, Massachusetts Federation of Women's Clubs	3
Boston Mineral Club	9
Brookline Bird Club	1
Children's Museum, Trustees	4
Greater Boston Orchestral Society	1
Institute for Religious and Social Studies	10
New England Botanical Club	8
N E Farm and Garden Association	9
Students' Branch, American Management Assoc	1
Women's Travel Club	1
Total	47

There was received from these Societies and from the Lowell Institute Cooperative Broadcasting Council and the Boston Society of Natural History for use of facilities, the sum of $593 16 The total expenditures, however, for operation were as follows

Custodian	$1,693 80	
Fuel	1,234 17	
Electricity (Light and Power)	432 80	
Elevator (Service and Repairs)	222 38	
Telephone	245 42	
Gas	17 32	
Water	51 40	
Equipment	600 36	
Upkeep	291 41	
Janitor's supplies and sundries	218 43	
Thomas H Gately's pension	600 00	
		$5,607 49
Receipts		593 16
Total Net Expenses		$5,014 33

The appropriations for the House Committee for the year 1945–1946 were·

Operation....	$3,600 00	
Additional salary to T L Redgate	450 00	
		$4,050 00

The House Committee recommends the adoption of revised Rules for the Use of the House as follows

Preamble to be revised and simplified

Section 4—Rule is modified by changing the rates charged for the use of the rooms as follows: For the use of the Assembly Room the rate is raised from $10 to $15 For the use of the Reading Room the rate is changed from $15 to $10, if no refreshments are served If refreshments are served, $5 additional will be charged Strike out in the second line "and the Reception Room" and also in the last line "for small groups" and insert "in special cases "

Section 5—The rules for keeping a visitors' book is stricken out as this rule has not been observed in the past.

Section 6—Substitute "House Committee" for "Assistant Librarian "

Section 7—Revise by striking out in the second line the words "introduced by fellows" and in the third line "and endorsed by the Council Societies," also strike out "not on the approved list should make" and in the same line "to the Assistant" and on the fifth line strike out "Librarian" and insert "House Committee should be made " Strike out the last two words "and in" and also strike out the last line

The rules will then read as follows

Rules for the Use of the House

Preamble

The Council wishes to encourage the use of the Academy House for meetings of learned and cultural societies in accordance with the following rules

Rules

1 The House of the Academy shall be available for the use of Fellows of the Academy at all reasonable hours

2. Except as otherwise provided, the privilege of using the House of the Academy shall be enjoyed by Fellows only, who shall, however, be permitted to bring guests with them to a number not exceeding twenty

3 Fellows introducing guests shall be responsible for any injury caused by them to the property of the Academy

4 Fellows or organizations introduced by them may use the Committee Room on the ground floor and also the Assembly Hall and the Reading Room For the use of the rooms on the ground floor no charges will be made For the use of the Assembly Hall a charge of $15 will be made for each occasion, for the Reading Room there will be a charge of $10 if no refreshments are served; or $15, if there are refreshments An additional charge of $5 will be made for each hour or fraction of an hour during which the rooms are occupied after 11 P M The House Committee is authorized, however, to reduce the charges in special cases

5 Fellows, or organizations introduced by them, desiring to use either of the two large rooms for a meeting shall make application to the House Committee not less than one week in advance of the time at which the meeting is to be held

6. The privileges of the House shall be limited to Fellows and their guests and to learned and cultural societies, approved by the House Committee Written application to the House Committee should be made at least two weeks in advance of the proposed meeting

Respectfully submitted,
Charles M Spofford, *Chairman*

May 14, 1947

REPORT OF THE COMMITTEE ON THE PERMANENT SCIENCE FUND

The Committee on the Permanent Science Fund recommended the following grants-in-aid which were approved by the Council of the American Academy of Arts and Sciences for the year 1946–1947

October 1946

1. To C. L. Hayward, Associate Professor of Zoology, Brigham Young University, Provo, Utah; for travel and publication expense in an investigation of the Ecology of Alpine Biotic Communities in western North America, $500.

2. To Seymour E Harris, Professor of Economics, Graduate School of Public Administration, Harvard College, for clerical assistance in extending a study of the Economic Aspects of the Release of Atomic Energy, $600

3 To Herbert L. Eastlick, Associate Professor of Zoology, State College of Washington, Pullman, Washington, for equipment, expendable materials, and publication of a study on the Embryology of Melanoblasts in the Silkie Fowl, $350

4. To C. C. Hoff, Assistant Professor of Zoology and Parasitology, Colorado Agricultural and Mechanical College, Fort Collins, Colorado, for studies on the Biota and Ecology of Certain Types of Montane Forests in Colorado, $200.

5 To T. H. Goodspeed, Professor of Botany and Director of the Botanical Garden, University of California, Berkeley, California, for services of an artist in Completing Preparation of a Monograph on Nicotiana, $550, contingent upon assurance that this aid will insure publication of same.

Total amount of grants-in-aid awarded October, 1946—$2,200

April 1947

1 To I Amdur, Associate Professor of Physical Chemistry, Massachusetts Institute of Technology, Cambridge 39, Massachusetts, for expendable materials and for assistance in continuation of an experimental study of atomic and molecular interaction potentials, $4,000

2 To T H Bissonnette, Professor of Biology, Trinity College, Hartford 6, Connecticut, for continuation of a study of photoperiodism in animals, $400

3. To C. J Goin, Instructor in Biology, University of Florida, Gainesville, Florida, for a genetic study on certain amphibia in Jamaica, $350

4 To H. B. Hitchcock, Associate Professor of Biology, Middlebury College, Middlebury, Vermont; for travel and expenses for a part of his study of the distribution and migration of *Myotis l. Lucifugus* and other bats, $450

5. To H. L. Movius, Jr., Assistant Curator of Palaeolithic Archaeology, Peabody Museum, Harvard University, Cambridge 38, Massachusetts, for a study of the significance and chronology of the Old Stone Age cultures within the territories of the U. S. S. R., $1,500

Total amount of grants-in-aid awarded April, 1947—$6,700.

Total number of grants for 1946–1947—10

Total amount of grants for 1946–1947—$8,900

Respectfully submitted,
JOHN W. M. BUNKER, *Chairman*

May 14, 1947

REPORT OF THE AMORY PRIZE COMMITTEE

After considerable discussion of the deferred award to Dr. Laqueur it was voted to be the opinion of the present committee that the award voted to him in 1941 is now due, should be paid to him in any fashion he desires, and should be publicly announced

Attention was given to the terms of the Amory award, considering the precise terms of this bequest, legal opinions regarding these terms, and understandings and precedents of the first Amory Prize Committee

It was the consensus of opinion that the donor desired primarily that the awards be made for the encouragement of work of immediate therapeutic relevance but that such work being not available, work indirectly important to the treatment of disorders of the reproductive organs in human beings should be recognized. It was agreed that fundamental researches throwing light on the function of any of the reproductive organs has such importance

It was further agreed that in case no single piece of work appeared to be of sufficiently great merit to justify awarding the entire prize to one individual, the available sum could most appropriately be divided into several lesser sums for individual awards

It was the consensus that, other things being equal, awards to younger investigators rather than to established proponents would be within the letter of the terms of bequest and would most nearly promote the expressed purpose of the donor.

It was recognized that only work done in the preceding seven years was to be considered in assigning awards

It was also decided that the funds should be awarded principally in the form of cash prizes, with some sort of relatively inexpensive scroll or certificate in addition (The terms of the bequest permit this procedure.)

It was further agreed that the traveling expenses of the recipient, incurred in attendance upon a meeting of the Academy for receipt of the awards, would be paid and that they would be entertained at dinner on the evening of the said meeting.

The Secretary reported that an announcement of the awards with requests for nominations had been published throughout the world and that letters had been sent to several men in the field of genito-urology, asking for nominations.

Those nominated to date number twenty-nine. Recommendations for the next award will be made to the Council after November 10, 1947 upon which date the current Septennium terminates

Respectfully submitted,
ROY G HOSKINS, *Secretary*

On the recommendation of the Treasurer, the Academy voted that the annual assessment for the year 1947–1948 for Resident Fellows be continued at fifteen dollars

The following officers and committees were elected for the coming year

Howard M. Jones .	*President*
Roland G. D Richardson	*Vice-President for Class I*
Irving W Bailey	*Vice-President for Class II*
Erwin N Griswold	*Vice-President for Class III*
Donald Scott	*Vice-President for Class IV*
John W. M. Bunker	*Corresponding Secretary*
Isadore Amdur	*Recording Secretary*
Horace S Ford	*Treasurer*
Frederick H Pratt	*Librarian*
Taylor Starck	*Editor*

COUNCILLORS FOR FOUR YEARS

Joseph H Keenan	Class I
Paul C Mangelsdorf	Class II
Harvey H Bundy	Class III
William G Constable	Class IV

COMMITTEE ON PERMANENT SCIENCE FUND

John W. M Bunker, *Chairman*

Roger Adams	Edward L Moreland
Kirk Bryan	Julius A Stratton
A Baird Hastings	Payson S Wild, Jr

FINANCE COMMITTEE

Ralph E Freeman	Henry P Kendall
Jerome C Hunsaker	Henry L Shattuck

RUMFORD COMMITTEE

Harlow Shapley, *Chairman*

Percy W. Bridgman	Joseph H Keenan
Arthur C. Hardy	Edwin H. Land
George R Harrison	Francis O Schmitt

C M. WARREN COMMITTEE

Frederick G Keyes, *Chairman*

Louis F. Fieser	Kenneth L Mark
Grinnell Jones	Avery A Morton
Charles A Kraus	Walter C Schumb

AMORY PRIZE COMMITTEE

Edwin B Wilson, *Chairman*

William B. Castle	George W. Thorn
Roy G. Hoskins	George B Wislocki
Gregory Pincus	S. Burt Wolbach

COMMITTEE OF PUBLICATION

Taylor Starck, *Chairman, ex officio*

Ernest H. Huntress	Class I
Kenneth V. Thimann	Class II

Thomas North Whitehead	Class III
Kenneth J Conant	Class IV

COMMITTEE ON THE LIBRARY

Frederick H Pratt, *Chairman, ex officio*

Raymond C Archibald	Class I
Charles A. Weatherby	Class II
Francis N Balch	Class III
Henry B. Washburn	Class IV

AUDITING COMMITTEE

Donald S Tucker   Thomas H Sanders

HOUSE COMMITTEE

Charles M Spofford, *Chairman*

Chester M Alter   H Addington Bruce

John B Wilbur

COMMITTEE ON MEETINGS

The President

The Recording Secretary

Bart J Bok   Arthur Clay Cope

Douglass V Brown   Henry B Phillips

A new member was introduced by a sponsoring Fellow

The following communication was presented.

Edward U Condon *The Work of the National Bureau of Standards*

The meeting was dissolved at 10 15 P M

One Thousand Three Hundred and Twentieth Meeting

OCTOBER 8, 1947 —STATED MEETING

The Academy met at its House at 8 20 P. M

The President in the Chair.

There were present forty-two Fellows

The records of the meeting of May 14 were read and approved.

The Corresponding Secretary reported the receipt of letters accepting Fellowship from 28 newly elected Fellows Howard Hathaway Aiken, David Lawrence Belding, Ruth Fulton Benedict, Richard Burgin, Thomas Dudley Cabot, Edward Uhler Condon, Paul Clifford Cross, John Dos Passos, Arnold Gesell, Sanford Burton Hooker, Mark DeWolfe Howe, Wilbur K Jordan, Milton Edward Lord, Ralph Lowell, Charles Winters MacGregor, Lewis Mumford, Norman Burdett Nash, John Lord O'Brian, William Phillips, Francis Minot Rackemann, Fritz Jules Roethlisberger, James Stevens Simmons, Richard Mason Smith. Merrill Clary Sosman, Clark Conkling Stephenson, William Freeman Twaddell, Shields Warren, Sumner Welles, from 10 Foreign Honorary Members: Paal Berg, Hamilton Alexander Rosskeen Gibb, Augustus Daniel Imms, P. Maheshwari, Edward Arthur Milne, Alf Erling Porsild, Meghnad N Saha, Sir George Paget Thomson, Godfrey Hilton Thomson, Wong Wenhao; also letters declining Fellowship from three newly elected Fellows: Hans Albrecht Bethe, Mildred McAfee Horton, Ivor Armstrong Richards.

He also announced that the Council had accepted with regret the resignations of Walter F. Dearborn, IV, 1, Walter Hunter, IV, 1, L Don Leet, II, 1, and that an error had been made in reporting the death of Louis E. Lapicque, Foreign Honorary Member, in the Council minutes of April 22.

The Fellows approved the action of the Council calling for a gift of $250 with a suitable document of presentation to Mrs M F Ball in recognition of more than twenty-five years of faithful service to the Academy.

New members were introduced by sponsoring Fellows

The President introduced the newly appointed Executive Officer, Ralph W. Burhoe, who told the Fellows of his future plans and solicited their cooperation in helping him to vitalize the Academy along the lines recommended in the Report on the Present Status and Future of the Academy

The principal business of the meeting was the consideration of the Report of a Special Committee on Revision of the Statutes The President outlined the major changes which had been made in revising the Statutes, The Corresponding Secretary reported that the Council had approved the revised Statutes as circulated to the Fellows and moved that the Academy proceed to approve the revised statutes Chapter by Chapter. The following actions were taken·

a Chapter I, approved.

b Chapter II, approved after discussion in which it was pointed out that the revised Statutes permitted an increase in the number of Fellows to one thousand without actually requiring expansion beyond the previous limit of eight hundred members. During the discussion it was pointed out that it would be desirable to revise the nomenclature of the classes and sections in the near future.

c Chapter III, approved

d Chapter IV, approved

e Chapter V, approved

f. Chapter VI, approved

g. Chapter VII, approved.

h. Chapter VIII, approved.

i. Chapter IX, approved with the substitution of "particular publications" for "special publications" at the end of Article 6 Several typographical errors were pointed out for correction During this discussion the Fellows were urged to make greater use of the publication facilities of the Academy for presentation of original contributions The Treasurer felt that the Academy funds were adequate to take care of considerable expansion of this portion of the Academy's publication activities

j Chapter X, approved

k. Chapter XI, approved

l. Chapter XII, approved A motion was lost calling for substitution of "but not less than 27" for "in a meeting of not less than forty Fellows" in the last sentence of Article 5

A motion to adopt the revised Statutes as amended was carried

The Corresponding Secretary, as secretary of a Special Committee on Implementing the Revised Statutes, presented the following motion

Moved That the Statutes as amended and enacted October 8, 1947, shall become effective following the next annual election of officers in May 1948, except that

(1) The Council, at its meeting on November 12, 1947, shall appoint an interim special Committee on Membership to serve until its successors are elected, as described in Chap XI (Revised), Art 1, Sec ii, with duties as specified in Chap III (Revised)

(2) The nomination and election of Fellows in May, 1948 shall be according to procedure as set forth in Chap III (Revised)

(3) The election of officers and Standing Committees in May, 1948 shall conform to the revised Statutes

(4) Chap VII (Revised) and Chap VIII (Revised) pertaining respectively to the Treasurer and the Librarian shall become effective immediately

(5) Chap IX, on the Editor and Publications, shall be put into effect after adoption of the revised Statutes

(6) Chap X, concerning the Council, shall become effective at once upon vote of the Council

Mr Shapley, chairman of the Rumford Committee, pointed out that due to the war, no Rumford premium had been awarded for four years and that it therefore might be necessary to award a premium retroactively to fulfill the conditions of the Rumford Trust calling for a biennial recommendation to the Council of a candidate for reception of the premium During the discussion, Mr Wyzanski pointed out that the Statutes did not call for Council approval of research grants in aid voted by the Rumford Committee.

A vote of thanks to the Special Committee on Revision of the Statutes was passed

The meeting was dissolved at 9 50 P M

One Thousand Three Hundred and Twenty-first Meeting

NOVEMBER 12, 1947 —STATED MEETING

The Academy met at its House at 8 15 P M

The President in the Chair

There were present forty-seven Fellows and thirty-three guests

The records of the meeting of October 8 were read and approved

The Corresponding Secretary reported the following actions of the Council

1 The designation of Walter F Dearborn, IV, 1, as Fellow Emeritus instead of acceptance of resignation as previously recorded

2 The acceptance with regret of the resignation of Karl Sax, II, 2

3 Authorization of the President to appoint an interim Committee on Membership to serve until the election of the regular Committee on Membership at the next annual election

4 Authorization of a joint Committee of the American Academy of Arts and Sciences and the Boston Museum of Science which will cooperate with other groups to encourage interest in science among secondary school students

The President invited the Fellows, on behalf of the Committee for the Arthur Dehon Little Memorial Lecture, to attend the Second Memorial Lecture on the topic, "Physics in the Contemporary World," at the Massachusetts Institute of Technology, November 25, 1947 The Lecturer, J. Robert Oppenheimer, is a Fellow of the Academy

New members were introduced by sponsoring Fellows.

The following communications on *Problems in Evolution* were presented

F. L Whipple *Some Current Trends of Thought Concerning Cosmic Evolution.*

A. S. Romer *Advances in the Study of Organic Evolution*

Bart J. Bok and F L Hisaw commented briefly on current research trends in astronomy and biology.

The meeting was dissolved at 10 20 P M

One Thousand Three Hundred and Twenty-second Meeting

DECEMBER 10, 1947 —STATED MEETING

The Academy met at the Georgian Room of the Statler Hotel at 7 00 P M

There was no scheduled business and the Corresponding Secretary acted as toastmaster in the absence of the President

This meeting had been designated as the Third Annual Dinner Meeting and Ladies' Night There were present, in addition to the speaker of the evening, fifty-five Fellows and their ladies

The Corresponding Secretary briefly addressed the meeting on the traditions of the Academy in introducing the speaker of the evening, George D Stoddard, President of the University of Illinois, whose communication was entitled *Science Serves Two Masters.*

The meeting dissolved at 9 30 P M

One Thousand Three Hundred and Twenty-third Meeting

JANUARY 14, 1948.—STATED MEETING

The Academy met at its House at 8 20 P M.

E N Griswold, Vice-President, in the Chair in the absence of the President

There were present twenty-nine Fellows and six guests

The records of the meetings of November 12 and December 10, 1947 were read and approved

The Corresponding Secretary reported

1. That A W Allen, II, 4, G P Baker, III, 3, and W H Claflin, Jr., III, 4, had accepted Fellowship and that G. A Shajn, I, 1, had accepted Foreign Honorary Membership.

2 That the Council had designated as Fellows Emeriti: W L Evans, I, 3, and F B Talbot, II, 4

3 That the President had appointed the following committees:

The Committee of Publication: K. B. Murdock to replace K J. Conant.

The Committee on UNESCO W G Constable, Hudson Hoagland, F. H Taylor, P S Wild, Jr, and I Amdur, chairman

The Committee on Popular Lectures· E N Griswold, Ralph Lowell, and E. C Kemble, chairman

Interim Special Committee on Membership Class I. J. L. Oncley, George Scatchard, Class II C A Janeway, R H. Wetmore, Class III R G Caldwell, J. R Killian, Jr., Class IV C J. Ducasse, W. F Twaddell.

4. That the Council had approved a recommendation of The Rumford Committee granting $550 to W F Meggers of the National Bureau of Standards.

A new member was introduced by a sponsoring Fellow

The following communication was presented

W J. Cunningham· *New England Transportation and Its Relation to the New England Economy*

Following the discussion of the communication, A P Usher spoke briefly on recent research trends in economics

The meeting was dissolved at 9 45 P M.

One Thousand Three Hundred and Twenty-fourth Meeting

FEBRUARY 11, 1948 —STATED MEETING

The Academy met at its House at 8 20 P M

The President in the Chair

There were present forty-four Fellows and one hundred and thirty guests

The records of the meeting of January 14 were read and approved

The Corresponding Secretary stated that there were no Council actions to report

Two new members were introduced by sponsoring Fellows

The following communication was presented

John von Neumann *Electronic Methods of Computation.*

The meeting was dissolved at 9 50 P M

One Thousand Three Hundred and Twenty-fifth Meeting

MARCH 10, 1948 —STATED MEETING

The Academy met at its House at 8 20 P M

The President in the Chair

There were present fifty-seven Fellows and one hundred and nineteen guests including A L von Muralt, President of the Swiss Academy of Natural Sciences

The records of the meeting of February 11 were read and approved

The Corresponding Secretary reported that the Council had approved appropriations totalling $19,405 for salaries, meetings and maintenance for the next fiscal year and had recommended the sum of $15 00 for the next annual assessment

The President announced the appointment of a Nominating Committee consisting of. R E Freeman, III, 3, chairman, G. J. Esselen, I, 3, C S Keefer, II, 4, W O Ault, IV, 2

Two new members were introduced by sponsoring Fellows

The communication entitled, *Peacetime Uses of Atomic Energy* was presented by three speakers as follows.

I *Problems of Power Development* E. R Gilliland, Professor of Chemical Engineering, Massachusetts Institute of Technology

II *Research Problems in the Physical Sciences* C. D Coryell, Professor of Chemistry, Massachusetts Institute of Technology.

III *Research Problems in the Medical Sciences* F D Moore, Assistant Professor of Surgery, Harvard Medical School

The meeting was dissolved at 10:00 P. M.

One Thousand Three Hundred and Twenty-sixth Meeting

APRIL 14, 1948 —STATED MEETING

The Academy met at its House at 8 23 P M.

The President in the Chair

There were present twenty-three Fellows and thirty-seven guests

The records of the meeting of March 10 were read and approved

The Recording Secretary, in the absence of the Corresponding Secretary, read the list of grants from the Permanent Science Fund made by the Council

A new member was introduced by a sponsoring Fellow

The following communication was presented

W G Constable: *The Painter's Workshop*

The meeting was dissolved at 9 45 P M

One Thousand Three Hundred and Twenty-seventh Meeting

MAY 12, 1948 —ANNUAL MEETING

The Academy met at its House at 8 26 P. M

The President in the Chair.

There were present fifty-three Fellows and about sixty guests

The records of the meeting of April 14 were read and approved

In the absence of the Chairman of the Rumford Committee, Harlow Shapley, Percy W Bridgman introduced the Rumford medallist for 1945, Edwin H. Land. The President presented Mr. Land with a gold and silver medal in conformity with the conditions of the award

The communications entitled *Theory and Application of Synthetic Polarizing Sheets* and *A Brief Description of the Functional Approach to One-step Photography* were presented by Mr Land

The Corresponding Secretary presented the following budget items which were approved by the Fellows

\$19,405 for items as presented at the March meeting, \$800 appropriation for addressograph and accessories; \$15 annual assessment for the year 1948–1949

The President read the following report on deaths, resignations, and the status of the membership

I regret to have to report the following deaths Twenty-three Fellows and three Fellows Emeriti—Elliott Carr Cutler (II· 4), Rollins Adams Emerson (II 2), Henry Thatcher Fowler (FE IV: 2), James Walter Goldthwait, (II 1), Evarts Boutell Greene (IV 2), Robert Almer Harper (II 2), Reid Hunt (FE II· 4), Ellsworth Huntington (II 1), Dunham Jackson (I 1), Henry James (IV 4), Grinnell Jones (I 3), Charles Atwood Kofoid (II 3), Frank Rattray Lillie (II 3), Thomas William Lamont (III 4), Alfred Church Lane (II 1), Burton Edward Livingston (II 2), William Ralph Maxon (II 2), James Vance May (III 4), John Bassett Moore (III 2), James Hugh Ryan (IV 1), William Isaac Thomas (III 3), Edward Sampson Thurston (III. 1), Alfred North Whitehead (FE I· 1), Herbert Percy Whitlock (II 1), Frank Clifford Whitmore (I 3), Clark Wissler (IV· 3), Eleven Foreign Honorary Members—Frederick Orpen Bower (II 2), Johannes N Bronsted (I 3), Léon Duguit (III· 1), Henri Guy (IV 4), Godfrey Harold Hardy (I 1), Paul Hazard (IV 4), Gustaf Adolf Frederik Molengraaff (II· 1), Max Planck (I 2), Rudolf Stammler (III: 1), S Rudolph Steinmetz (III: 3), Peter Bernhardovich Struve (III 3)

Four Fellows have resigned Walter Samuel Hunter (IV. 1), Lewis Don Leet (II. 1), Robert P Patterson (III: 1), Karl Sax (II. 2)

Nine Fellows have been classed as Emeriti As of May 1, 1947—William James Cunningham (III 3), Walter Fenno Dearborn (IV 1), William Lloyd Evans (I· 3), George La Piana (IV· 2), Elton Mayo (III· 3), Hervey Woodburn Shimer (II 1), Henry Bradford Washburn (IV· 1), As of May 1, 1948—Robert Bayley Osgood (II 4), Fritz Bradley Talbot (II 4).

In May 1947, the election by the Council of thirty-four Fellows and thirteen Foreign Honorary Members was announced to the Academy; all except three Fellows (Hans Albrecht Bethe, Mildred McAfee Horton, Ivor Armstrong Richards) and one Foreign Honorary Member (I M. Vinogradov) accepted election.

The roll now includes 762 Fellows, 32 Fellows Emeriti, and 117 Foreign Honorary Members (exclusive of those elected in 1948)

The following annual reports were read and approved

REPORT OF THE TREASURER

(*Extract*)

*Receipts, 1947–1948

Academy, General			
Investment Income	$32,042 51		
Less Income to Special Funds	15,276 80		
		$16,765 71	
Use of Facilities		2,403 96	
Assessments and Admission Fees		6,602 50	
Transfer of Unexpended Appropriations		676 63	
			$26,448 80
Mabel S Agassiz Fund			
Investment Income			108 80
Amory Prize Committee			
Investment Income			3,987 00
Kennelly Fund			
Investment Income			82 00
Library Sale Fund			
From Linda Hall Library Trustees			180,000 00
Life Membership Fund			
From Daniel L Marsh and Sarah Wambaugh			400 00
Permanent Science Fund			
Boston Safe Deposit and Trust Co , Trustee		$11,894 05	
Return of Grant		350 00	
Investment Income		2,975 00	
			15,219 05
Publications Committee			
Investment Income		$2,818 00	
Sale of Publications		512 24	
Lake Publications		662 50	
			3,992 74
Rumford Committee			
Investment Income		$4,305 00	
Return of Grant		43 77	
			4,348 77
School Science Fund			
Boston Society of Natural History			250 00
Special House Alterations Fund			
Fire Loss and Sales			724 00
C M Warren Committee			
Investment Income			1,001 00
Total Receipts			$236,562 16

* Excluding sales of securities

*Expenditures, 1947–1948

Academy, General			
Salaries and Pensions		$9,067.02	
Meetings and General Administration		3,350.74	
House Maintenance		3,976.64	
President's Expense		143.80	
Treasurer's Expense		713 81	
Special Appropriations			
Alterations	$5,071 00		
School Science Fund	250 00		
		5,321 00	
			$22,573 01
Mabel S Agassiz Fund			
For Meetings			108 80
Amory Prize			
Deferred Award		$4,300 00	
Expense		157 27	
			4,457 27
Carnegie Corporation, for Visual Arts Conference			97 34
Library Sale Fund			
Boxes, Express, Storage, etc.			3,077 46
Permanent Science Fund			
Grants		$6,700.00	
Expense		5 39	
			6,705 39
Publications Committee			
General		$944 75	
Lake		10 59	
			955 34
Rumford Committee			
Grants		$1,300 00	
Medals		591 49	
Expense		160 50	
			2,051 99
School Science Fund			63 63
Special House Alterations Fund			8,040 51
C M Warren Committee			
Grants			750 00
Total Expenditures			$48,880 74

REPORT OF THE RUMFORD COMMITTEE

Three grants in aid of research have been made during the year 1947–1948 as follows.

To Dr Stefan L Piotrowski, of Cracow, Poland, $500, to assist in the construction of a photoelectric photometer for work on eclipsing binaries in cooperation with the International Astronomical Union's Panel on Eclipsing Binaries

To Dr William F Meggers, of the National Bureau of Standards, Washington, D C , $550, to assist in spectroscopic researches at the Bureau of Standards by Professor Catalán of Madrid, Spain

* Excluding purchases of securities

To Dr. Francis Birch, of the Harvard Geophysical Department, $400, to assist in preparing conductivity specimens from rocks from the Alva B Adams Tunnel

Awards of the Rumford Premiums and Medals were made as follows: for 1945 to Edwin H Land for his pioneer work on Polaroid and its applications, for 1947 to E Newton Harvey of Princeton, New Jersey, for his work on animal luminescence

The Assistant Treasurer of the American Academy reports a balance on hand on March 8, 1948, of $20,064.89

The estimated investment income for 1948–1949 is $4,535. The total available for appropriation is $24,599 89

Respectfully submitted,
HARLOW SHAPLEY, *Chairman*

May 12, 1948

REPORT OF THE CYRUS M WARREN COMMITTEE

The Committee had available for grants during 1947–1948 the sum of $1000 00 which amount was voted for awards at the meeting on March 12, 1947

The following grants were made, after consideration by the Committee, of the applications submitted

To Doctor Charles L Bickel of the Phillips Exeter Academy, a grant of $150 00 to provide supplies and perhaps apparatus for research problems in organic chemistry

To Professor L V Coulter of Boston University, a grant of $300 00 for the construction of apparatus in connection with a study to determine the effect of molecular structure on hydrogen bond strengths

To Professor A. E Martell of Clark University, a grant of $300 00 to assist in the purchase of apparatus for use in an investigation involving electrical conductivity measurements of dilute non-aqueous solutions

A letter was received from Professor Martell reporting on the purchase of apparatus and the progress of the research program, and expressing his thanks and that of Clark University to the Cyrus M Warren Committee for the assistance

A letter from Doctor Bickel reports on the progress of his research project One problem has been completed and a manuscript based on the work has been accepted for publication

Respectfully submitted,
FREDERICK G KEYES, *Chairman*

May 12, 1948

REPORT OF THE COMMITTEE OF PUBLICATION

The Committee has held only one meeting during the year though there was some exchange of information and opinion by correspondence and orally.

No monographs or books were submitted for publication during the year

This is the first year under the new Statutes which require the publication of a Summer and a Winter number of the Proceedings, each of which is to include certain material As the Academy did not begin to operate under the new Statutes until the fall, the Winter number, now in press, will be distributed to members only this month The Summer number, part of which is in type, should be ready in September These two numbers will conclude Volume 76 Hereafter the Winter number will appear as soon as possible after the December meeting, the Summer number after the Annual meeting

Beginning with January, 1948, five monthly numbers of the Bulletin have been issued In the ensuing year the statutory number of eight will be published All the work entailed by this publication has been accomplished by the Executive Officer of the Academy, Mr Ralph Burhoe

The manuscript of a *Study of Massachusetts Facilities for Child Health,* mentioned in the last report, has not yet been submitted

The expenditures for 1947–1948 were only $772 46 However the cost of two numbers of the Bulletin and of the two numbers of the Proceedings will appear in the statement for 1948–1949 The new year will also see the full volume of eight Bulletins that we estimate will cost about $1,100 The expenses for the past year were therefore abnormally small The reserve balance of $11,832 and the estimated $2,750 income from investments provide a substantial backlog to meet unforeseen expenses or increases in the printing costs We may also count on a certain amount from sales of publications In the past year this item was $429 07 and we may expect the sales to continue at approximately the same rate Funds are therefore available for the publication of all acceptable manuscripts that are likely to be presented within the coming twelve months

The Editor has discussed with the Publication Committee and the Executive Officer the advisability of soliciting manuscripts for publication We feel that the Fellows have gotten out of the habit of thinking of the Academy when they have manuscripts for publication We propose to call the attention of the members to the advantages of publication in the Proceedings and the Memoirs through a note in the October number of the Bulletin We should constantly have on hand material for one full number of the Proceedings This would not delay publication as long as it is delayed by most professional journals, some of which are two years or more in arrears Our aim is to achieve prompt and regular issuance of the Proceedings and to cover all the fields of interest in rotation Obviously this goal cannot be attained unless manuscripts are regularly submitted from all classes and sections of the Academy.

Respectfully submitted,
TAYLOR STARCK, *Chairman*

May 12, 1948

REPORT OF THE LIBRARY COMMITTEE

Following the sale, so skillfully organized by Mr Metcalf, of our main holdings to the Linda Hall Library of Kansas City, the small remainder of some 650 early volumes has been disposed as follows.

The greater part—a bequest of our first President, Governor James Bowdoin—has been deposited at Bowdoin College, where much valuable Bowdoin material is already attractively housed The Boston Athenaeum, where for many years our library had its home, is again the custodian of the great folio sets given by John Adams and bequeathed by Benjamin Franklin, respectively Further, a number of 18th century editions of the classics given by Francis Vergnies de Bonischere, once a prominent physician of Newburyport, are now at the Essex Institute of Salem

It is believed the above assignments are such as to afford especially appropriate settings for these permanent loans, and at the same time to render them of most use to scholars Our reading room will still retain a few shelves of books representative of miscellaneous early donors

Mrs Mabel Frothingham Ball's retirement after twenty-five years as Assistant Librarian calls for more than usual notice from the Academy Her service, not only as a trained librarian but as a general exceutive secretary, has been uniformly faithful—at times even in the face of almost mortal illness The detailed grasp of Academy affairs, past and present, that she acquired has of late been of invaluable aid in the institution of our new executive department

With this occasion the traditional library administration comes to an end, but it gratifying to note the perpetuation of the post of Librarian, under which a number of important functions related to income and outgo of published material are bound to call for continued attention The retiring Librarian would express to his fellow members of the Committee his utmost gratitude for their unstinted helpfulness and generous counsel during these years of transition

Respectfully submitted,

FREDERICK HAVEN PRATT, *Chairman*

May 12, 1948

REPORT OF THE HOUSE COMMITTEE

The use of the House by other organizations, as recommended by the Mather Commission report, has increased greatly during the year. An indication of this is shown in the increase from $205, for the previous year, to $2,404, in the present year, in re-imbursement for the use of our facilities The Co-operative Broadcasting Council of the Lowell Institute has continued to occupy 1,200 square feet on the fourth floor, and the second and third floors of the stacks are still being occupied by the Library of the Boston Museum of Science. The organizations in addition to the Acedemy using the facilities for meetings are listed below

	Number of Meetings
American Association of University Women	1
American Institute of Decorators .	3
Antiques Committee, Massachusetts State Federation of Women's Clubs	3
Boston College Institute of Adult Education	15
Boston Mineral Club	3
Boston Society of Civil Engineers	2
Boston Teachers Union	9
Brookline Bird Club	2
Children's Museum	4
French Center of New England	15
Herbert Read Lecture (Institute of Contemporary Art, M I. T, etc)	1
Institute of Religious and Social Studies	6
Joyce Kilmer Post, American Legion	9
Lowell Institute Co-operative Broadcasting Council	1
New England Botanical Club	9
New England Farm and Garden Association	7
Pan American Society	3
Radcliffe Alumnae	1
Soil Conservation Society	1
Total number of meetings (of 19 societies)	95

About 7,500 persons attended meetings at the Academy held by outside organizations.

Besides the regular meetings of the Academy, there have been about 50 meetings of various committees and sub-committees of the Academy at the House

During the year the remainder of the library books sold to the Linda Hall Library were shipped and the top three floors of the library stack wing are now essentially empty of our books During the year a petition for use of these top three floors by an outside organization was declined on account of expense involved and the uncertainty of the Academy's own needs

Further alterations and renovations of the House continued The Reading Room was cleaned and painted, and new lighting was installed, the two front rooms on the first floor were converted to office space, the main portion of the first floor was altered to make it suitable for an exhibit hall, the closet room adjacent to the Reading Room was equipped with a sink to make it more useful in connection with serving refreshments and buffet style meals in the Reading Room, the former office of the Librarian was converted to a conference room

The expenditures of the House Committee for regular operations totalled $6,772 65, as listed below

House Maintenance	
Coal	$1,024 08
Gas	22 05
Electricity	900 74
Elevator	545.34
Water .	39.00
Equipment	298.45
Supplies and Repairs	600.97

Fire Insurance	$543 60
Telephone	262 94
Caretaker	1,933 07
Pensions	600 00
Miscellaneous	2 41
Total	$6,772 65

The appropriation for the House Committee was $5,600, in addition to which there was an income of $2,403 96 for the use of facilities, making a total of $8,003 96, and leaving unexpended, $1,231 31

For special alterations there was expended $8,040 51 Made available for this was a total of $12,477 73, consisting of the following

Balance remaining of first appropriation for special alterations	$6,682 73
Receipts for sale of stacks	500 00
Receipts for fire loss of equipment loaned	224 00
Appropriation by Council for further alterations	5,071 00
Total	$12,477 73

This leaves $4,437 22 unexpended balance of the funds for special alterations. The Committee revised Section 4 of the Rules for the Use of the House to read as follows.

"Fellows may use the Committee Room on the third floor without charge For the use of this room by others, the charge will be $5 00 For the use of the Assembly Hall, a charge of $15 00 will be made for each occasion, for the Reading Room, there will be a charge of $10 00 if no refreshments are served, or $15 00 if there are refreshments An additional charge of $5 00 will be made for each hour or fraction of an hour during which the rooms are occupied after 11 P M. The House Committee is authorized, however, to reduce the charges in special cases"

In closing I wish to pay tribute to the excellent service rendered by our Executive Officer Mr Burhoe, whose energy, ability and vision simplify greatly the work of the House Committee

Respectfully submitted,

CHARLES M SPOFFORD, *Chairman*

May 12, 1948

REPORT OF THE COMMITTEE ON THE PERMANENT SCIENCE FUND

The Committee on the Permanent Science Fund awarded eight grants-in-aid for a total of $4,400 during the fiscal year 1947–1948, as follows.

1 To Elso S Barghoorn, Assistant Professor of Botany and Curator of Paleobotany, Harvard University, Cambridge 38, Mass , for a paleobotanical study of lignite in Vermont, $600

2. To Charles T. Brues, Professor of Entomology, Emeritus, Biological Laboratories, Harvard University, Divinity Avenue, Cambridge 39, Mass , for further classification of insects in amber, $615

3. To Lincoln Constance, University of California, Visiting Professor at Harvard University, Acting Director of Gray Herbarium, Cambridge 38, Mass , for travel for field study in Texas on the mode of origin of certain wild plant species, $350

4 To Kenneth J Conant, School of Design, Harvard University, Cambridge 38, Mass , for aid in a three dimensional study of a Mediaeval Monastic group which formerly existed at Cluny in Burgundy, $425

5 To Hallam L Movius, Jr , Peabody Museum, Harvard University, Cambridge 38, Mass , for a supplementary grant for his study of Paleolithic Culture in the U S S. R , publication of which has been assured from another source, $750.

6 To Bernard F Riess, Department of Animal Behavior, American Museum of Natural History, 135 Cushman Road, Scarsdale, New York, for aid in a study of relation of diet to susceptibility to audiogenic and stress shock, $1,000

7 To Alexander Forbes, Harvard Medical School, 25 Shattuck Street, Boston, Mass , for continuation of study of refractory phase in cerebral mechanism, $300

8 To William M Ingram, Department of Zoology, Mills College, Oakland 13, California, for completion of a study of "Fossil and Recent Cypraeidae of the Eastern Regions of the Americas," $360

The Committee, for its own guidance, has formulated certain principles in respect to recommending grants-in-aid, as follows

In general, it favors granting support to individuals rather than to organizations, although grants are permissible to public or private associations, societies or institutions

Special consideration is deemed to be appropriate for projects on new frontiers of science, those which lie between or include two or more recognized fields, and to those proposed by investigators who may be on the threshold of investigational careers, or who are handicapped by lack of resources

The Committee ordinarily does not approve grants for the purchase of non-expendable equipment of a type which can usually be expected of an institutional laboratory, but does recognize that for special purposes, regular or special equipment may be needed and approvable

The Committee believes that the purpose of the Fund can best be served by something of the order of 10 grants per year, not exceeding $1,500 each, although it is aware of the accumulated funds which make possible support of a limited number of large projects

Respectfully submitted,

JOHN W M BUNKER, *Chairman*

May 12, 1948

REPORT OF THE AMORY PRIZE COMMITTEE

The Committee on the Amory Prize met five times

(1) May 7, 1947 A report was prepared for submission to the Council recommending the Prize to six persons, viz , Drs Dorfman, Huggins, Kenyon,

Kochakian, Marrian, and Olive Smith The report was rejected by the Council on the ground that the Septennium did not expire until November 10, 1947, and recommendations were not in order until after that date

(2), (3) January 14 and 26, 1948 The Committee took up the rejected report, reread the Amory will, decided to place more emphasis on studies close to therapy, drew up a list of persons who should be considered for the prize, and parcelled out among the members those whose contributions each should investigate

(4) February 11, 1948 The Committee members reported their findings, there was ample discussion, a list of six persons, viz, Drs Huggins, Marrian, Waksman, Papanicolaou, Kolff and Gutman (who had the cooperation of his wife) was adopted in that order but without prejudice or preference as to relative merit, a report to the Council was prepared recommending that the prize be equally divided between these six and that certain arrangements be made as tokens of the esteem in which they were held by the Academy The report was referred by the Council for legal advice, upon receipt of which it was recommitted to the Committee with a copy of the legal opinion

(5) May 5, 1948 The Committee members studied and discussed the legal opinion, in which they were much disappointed, and formulated a new report recommending the same six persons for the prize and leaving to the Council the determination of the amounts of the prizes and the arrangements for distributing them The amount available for the prizes is reported to be $23,289 less whatever may be appropriately deducted for administrative expenses

Respectfully submitted,

May 12, 1948 EDWIN B WILSON, *Chairman*

It was voted to send a note of appreciation to Frederick H Pratt for his long service to the Academy as Librarian

The annual election of officers and committees was held The Fellows proposed by the Nominating Committee were elected to office as follows

Howard M Jones	*President*
Roland G D Richardson	*Vice-President for Class I*
Irving W. Bailey	*Vice-President for Class II*
Robert B Stewart	*Vice-President for Class III*
Donald Scott	*Vice-President for Class IV*
John W M Bunker	*Secretary*
Horace S. Ford	*Treasurer*
Henry R Viets	*Librarian*
Taylor Starck	*Editor*

COUNCILLORS TO SERVE FOUR YEARS

Isadore Amdur	*Class I*
Arlie V. Bock	*Class II*
Keyes DeW Metcalf	*Class III*
Crane Brinton	*Class IV*

HOUSE COMMITTEE

Chester M. Alter, *Chairman*

H Addington Bruce — John B Wilbur

COMMITTEE ON MEMBERSHIP

The President, *Chairman, ex officio*

To serve for one year		*To serve for two years*
J Lawrence Oncley	*Class I*	George Scatchard
Charles A Janeway	*Class II*	Ralph H Wetmore
Robert G Caldwell	*Class III*	James R Killian, Jr
Curt J Ducasse	*Class IV*	W Freeman Twaddell

COMMITTEE ON MEETINGS

The President, *Chairman, ex officio*

The Secretary, *ex officio*

Bart J Bok — Arthur Clay Cope

Douglass V Brown — Henry B Phillips

COMMITTEE ON FINANCE

The Treasurer, *Chairman, ex officio*

Ralph E Freeman — Henry P Kendall

Jerome C Hunsaker — Henry L Shattuck

AUDITING COMMITTEE

Thomas H Sanders — Donald S Tucker

COMMITTEE ON PUBLICATION

The Editor, *Chairman, ex officio*

Ernest H Huntress — Kenneth V Thimann

Kenneth B Murdock — Thomas North Whitehead

PERMANENT SCIENCE FUND COMMITTEE

John W M Bunker, *Chairman*

Kirk Bryan — Edward L Moreland

Gustavus J Esselen — Julius A Stratton

A Baird Hastings — Payson S Wild, Jr

RUMFORD COMMITTEE

Harlow Shapley, *Chairman*

Percy W Bridgman — Joseph H Keenan

Arthur C Hardy — Edwin H Land

George R Harrison — Francis O Schmitt

C M WARREN COMMITTEE

Frederick G Keyes, *Chairman*

Edwin J Cohn — Charles A Kraus

Louis F Fieser — Avery A Morton

Hudson Hoagland — Walter C Schumb

AMORY PRIZE COMMITTEE

Edwin B Wilson, *Chairman*

William B Castle — George W Thorn

Roy G Hoskins — George B Wislocki

Gregory Pincus — S Burt Wolbach

New Fellows and Foreign Honorary Members were elected to the Academy as follows

FELLOWS

CLASS I, SECTION I

William Ted Martin	Cambridge
Hassler Whitney	Cambridge
Oscar Zariski	Cambridge

Class I, Section 2

Enrico Fermi	Chicago, Ill
Bruno Benedetto Rossi	Cambridge
Julian Seymour Schwinger	Cambridge
Victor Frederick Weisskopf	Cambridge

Class I, Section 3

Carl Ferdinand Cori.	St Louis, Mo
Charles duBois Coryell	Cambridge
Vincent du Vigneaud	New York, N. Y
Robert Burns Woodward	Cambridge

Class I, Section 4

John Chipman	Cambridge
Ivan Alexander Getting	Cambridge
Edwin Richard Gilliland	Cambridge
Hoyt Clarke Hottel	Cambridge
William Henry McAdams	Cambridge
Thomas Kilgore Sherwood	Cambridge
Theodor von Kármán	Pasadena, Cal
Walter Gordon Whitman	Cambridge

Class II, Section 1

Arthur Francis Buddington	Princeton, N J.
Adolph Knopf	New Haven, Conn
George Gaylord Simpson	New York, N Y

Class II, Section 2

Edward Sears Castle	Cambridge
William Jacob Robbins	New York, N Y
William Randolph Taylor	Ann Arbor, Mich
Frits Warmolt Went	Pasadena, Cal

Class II, Section 3

Edward Adelbert Doisy	St. Louis, Mo
Wallace Osgood Fenn	Rochester, N Y
Herbert Spencer Gasser	New York, N Y
Edmund Newton Harvey	Princeton, N J
Hubert Bradford Vickery	New Haven, Conn
George Wald	Cambridge
Sewall Wright	Chicago, Ill

Class II, Section 4

Francis Gilman Blake	New Haven, Conn
Allan Macy Butler	Boston
Edward Delos Churchill	Boston
John Rock	Boston

Class III, Section 1

Charles Allerton Coolidge	Boston

Class III, Section 2

William Lockhart Clayton	Washington, D. C
Howard Eugene Wilson	New York, N. Y

Class III, Section 3

Richard Bissell, Jr	Cambridge
Bishop Carleton Hunt	Boston

Class III, Section 4

Erwin Dain Canham	Boston
Charles Woolsey Cole	Amherst
Robert Cutler	Boston
Herbert John Davis	Northampton
Dwight David Eisenhower	New York, N Y
Carl Stephens Ell	Boston
Francis Calley Gray	Boston
Paul Gray Hoffman	Washington, D C
Carl Tilden Keller	Boston
David Eli Lilienthal	Washington, D C
Alfred Pritchard Sloan, Jr	New York, N Y
Henry Merritt Wriston	Providence, R I

Class IV, Section 1

Rudolph Carnap	Chicago, Ill
Frederick May Eliot	Boston
Arthur Edward Murphy	Ithaca, N Y
Hans Reichenbach	Los Angeles, Cal
Alfred Tarski	Berkeley, Cal

Class IV, Section 2

Margaret Mead	New York, N Y

Class IV, Section 3

Bernard Bloch	New Haven, Conn
Leonard Bloomfield	New Haven, Conn
Yuen Ren Chao	Berkeley, Cal
Berthold Louis Ullman	Chapel Hill, N C

Class IV, Section 4

Bartlett Harding Hayes, Jr.	Andover
Edward Hopper	New York, N. Y
John Marin	Cliffside Park, N J
Thomas Munro	Cleveland, O
Erwin Panofsky	Princeton, N J
Bruce Simonds	Hamden, Conn
John Sloan	New York, N Y

FOREIGN HONORARY MEMBERS

Class I, Section 2

Max von Laue	Göttingen
Arnold Sommerfeld ..	Munich

Class I, Section 3

Sir Robert Robinson ..	Oxford
The Svedberg ..	Upsala

Class II, Section 2

P. Boysen-Jensen	Copenhagen
Birbal Sahni	Lucknow, India

Class II, Section 3

Charles Herbert Best	Toronto
Archibald Gowanlock Huntsman	Toronto

Class III, Section 1

Léon Julliot de la Morandière	Paris

Class III, Section 2

José d'Almada	Lisbon

Class IV, Section 4

Jean-Marie Carré	Paris
Diego Rivera	Coyacan, Mexico
Jan Hendrik Scholte.	Amsterdam

The meeting dissolved at 10·07 P M

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B. Index to Affairs of the American Academy of Arts and Sciences